MACHINE LEARNING PREDICTION TO IMPROVE OPERATIONAL RESILIENCE IN MANAGING DISINFECTION FOR MACARTHUR WATER SUPPLY SYSTEM

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KEYWORDS

Water quality, total chlorine residual, predictive analytics, machine learning.

ABSTRACT

Resilience to drought and changing raw water quality is essential in managing distribution water quality to meet customer needs and regulatory requirements. To provide greater certainty of operating a complex distribution system fed by multiple sources, UTS Data Science Institute in collaboration with Sydney Water and TRILITY has developed a machine learning predictive model. This model predicts the travel time, total chlorine and the operational protocols of the distribution system to ensure effective disinfection. The model has been validated with compliance data and will be further validated with online total chlorine analysers. This model will assist Sydney Water to better manage disinfection from the water filtration plant to the customer's tap.

INTRODUCTION

Disinfection is a key barrier in a multi-barrier approach to providing safe, clean drinking water to customers. In general, systems that involve more compact distribution systems and lower detention times (either through shorter distance or higher levels of demand), employ chlorine as the primary disinfectant as it is highly effective in such systems. Alternatively, dosing free chlorine plus ammonia at optimal pH and mixing conditions to form the dominant monochloramine compound provides a disinfectant that is more persistent over longer durations. Where monochloramine is employed as the primary disinfectant, customer complaints relating to taste and odour also tend to be lower as it is more amenable in drinking water than chlorine.

Macarthur Water Filtration Plant (WFP), approximately 50km south-west of Sydney, is in the unique situation where it performs both disinfection strategies. Treated water after filtration is disinfected with gaseous chlorine before entering two 15ML storage tanks. Free chlorine leaving the tanks is monitored online and maintained at 1.4 mg/L (±0.15 mg/L) with the option of a standby chlorinator. From here, water is drawn to the township of Appin. Beyond the offtake to Appin, chlorine and ammonia are added to achieve a total chlorine residual of 1.7 mg/L (±0.15 mg/L), at a dose ratio of 4:1 (chlorine to ammonia). Water is then transferred via 17km long 1200mm steel cement lined trunk main to service approximately 300,000 Sydney Water customers in the wider Campbelltown area (Figure 1). The Macarthur Delivery System includes 17 reservoirs and supplies water in 25 separate pressure zones. Water flow across the main reservoirs is depicted roughly in Figure 2.

This work has been designed collaboratively among UTS Data Science Institute, Sydney Water, and TRILITY to determine where the opportunities exist to optimise process control and monitoring feedback that will result in greater consistency in total chlorine residual. Previously, UTS Data Science Institute, Sydney Water and Veolia have studied the Woronora Delivery System and built an analytics model for water quality prediction (Peters et al., 2020). Furthermore, the developed water quality prediction model has been calibrated and extended to make optimal plans to ensure water supply continuity and the quality of the water supplied during the dry season (Peters et al., 2021). There are some differences between the Woronora and Macarthur Delivery Systems. One key difference is in terms of disinfection regimes: the Woronora Delivery System is chloraminated while Macarthur WFP delivers both chlorination and chloramination.

METHODOLOGY

A quantitative model that links the upstream operational decisions and external influences on the water quality of the downstream customer connection points was detailed by Peters et al., 2020. Generally speaking, the modelling can be divided up into reticulation network that extends from the reservoirs to the customers, and the trunk network that links the WFP to the downstream reservoirs and pumping stations. In modelling water quality within the reticulation network only the total chlorine residual, as the disinfectant, was considered. In order to construct the model, an initial factor analysis was performed to identify the key relationships between the available data and confirm assumptions regarding the causal influences, which was followed by the construction of a parametric Bayesian model. As a critical input to the parametric decay model, the travel time was estimated using standard hydraulic flow simulators by first computing the flow rates on each pipe segment, followed by a path tracing algorithm to compute the total travel time.

As illustrated in Figure 3, the proposed solution consists of several main modules including network topology modelling, water travel time estimation for the trunk network and the distribution system, water quality modelling, total chlorine prediction, etc. Network topology modelling aims to connect different types of assets within the Macarthur Delivery System. By incorporating the status of point assets, it defines how water flows within the trunk network and each network distribution system. Then water travel time can be estimated using the simulated network structure and related reading data. Water travel time and total chlorine measured at reservoirs and compliance sites are used to investigate the total chlorine decay in transit and model water quality using machine learning. The trained model can be used to predict total chlorine across the whole Macarthur Delivery System.

RESULTS

To conduct network topology modelling, two types of zones, namely Storage Zone and Flow Zone, have been defined. A Storage Zone (see squares in Figure 4) has one or more hydraulically connected internal storage reservoirs and does not have any connected customers. A Flow Zone (as indicated by circles in Figure 4) represents a collection of connected pipes that does not have any internal storage and may supply water to customers. Flow Zones typically represent reduced pressure zones, demand management areas, or remainder zones and are typically separated by flowmeters. Based on the defined zones, a macroscopic network topology has been constructed as shown in Figure 4. Furthermore, the simulated trunk routes between reservoirs based on network topology modelling are shown in Figure 5.

The estimated water travel time between adjacent reservoirs is shown in Table 1, where the accumulated water travel time from the WFP is also included. With regards to reticulation travel time estimation, a challenge within the Macarthur Delivery System lies in more than one water source feeding a reservoir zone. In other words, some customers are supplied from one source but the remaining customers within the same reservoir zone may be supplied from another source. Taking the Rosemeadow reservoir zone as an example, certain areas receive water from the depleting Rosemeadow reservoir while other areas are directly fed from Sugarloaf (source water) at the time the Rosemeadow reservoir receives water. The estimated water travel time for Rosemeadow reticulation network is shown in Figure 6.

To identify the driving factors affecting total chlorine residual, we investigate the correlation between the total chlorine at downstream tap sites and a series of measurements (total chlorine, temperature, pH, ammonia, chlorine/ammonia ratio, turbidity) at upstream reservoirs. As can be seen from Figure 7, the total chlorine at downstream customer tap sites has a positive correlation with total chlorine and chlorine/ammonia ratio at reservoirs, negative correlation with temperature at reservoirs, but little correlation with pH, ammonia, and turbidity at reservoirs. Both total chlorine and temperature at reservoirs are considered when developing total chlorine prediction model.

Based on water travel time and temperature, multiple exponential decay models are trained to link total chlorine at downstream customer tap sites and upstream water source. Take a few reservoir zones as illustration, the trained machine learning models for total chlorine prediction are visualised (3D and 2D) in Figure 8. It shows how total chlorine decays with water travel time and temperature, respectively. As noted, different decay behaviours are observed for different zones. The model performance is validated with compliance data. Moreover, the mean absolute error based on 10-fold cross validation is calculated for the purpose of quantitative evaluation, which is shown in Figure 9. The overall mean absolute error is about 0.27.

By using water quality data from reservoirs, estimated water travel time, and mean temperature of summer and winter season, we could conduct water quality prediction for the whole reticulation area. Specifically summer temperature is calculated as the average temperature from December to February for the last two years while the winter temperature is calculated across June, July, and August. The prediction results are shown in Figure 10.

CONCLUSION

Maintaining water quality throughout the water distribution system to the customers' tap is essential. This paper has proposed a data-driven solution to predict total chlorine for the Macarthur Delivery System. The solution predicts the travel time, total chlorine and the operational protocols for the distribution system to ensure disinfection. The model has been validated with compliance data and plans to be further validated with online total chlorine monitors. This model will assist Sydney Water to improve operational resilience in managing disinfection from the water filtration plant to the customer's tap. The model can be used to ensure resilience for extreme weather impacts.

REFERENCES

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Peters, A., Tian, H., Liang, B., Li, Z., Doolan, C., Vitanage, D., Norris, H., Simpson, K., Storey C., Wang, Y., Chen, F. 2021. Water quality prediction in a chloraminated system for drought resilience. Ozwater'21

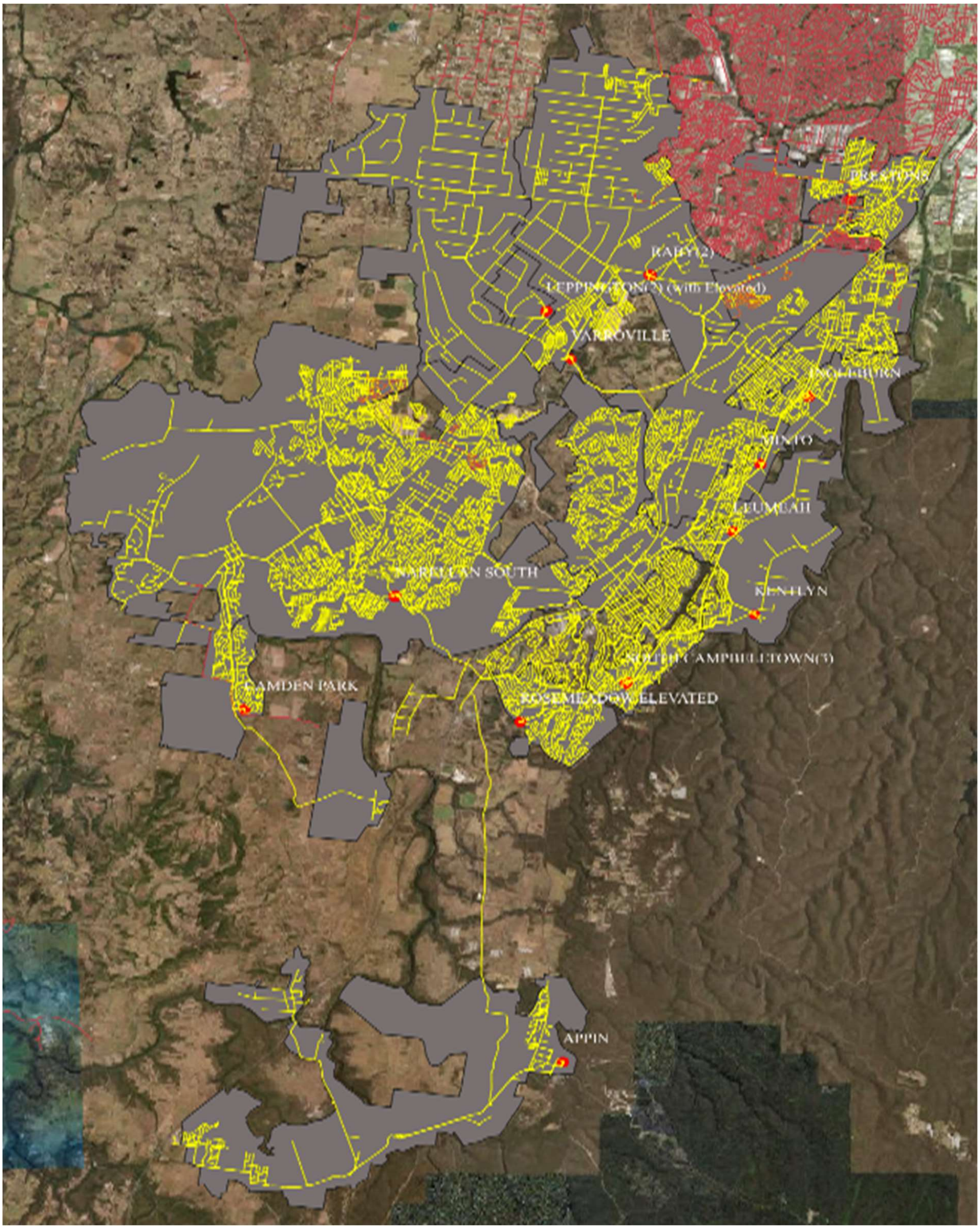


Figure 1: The Macarthur Water Delivery System

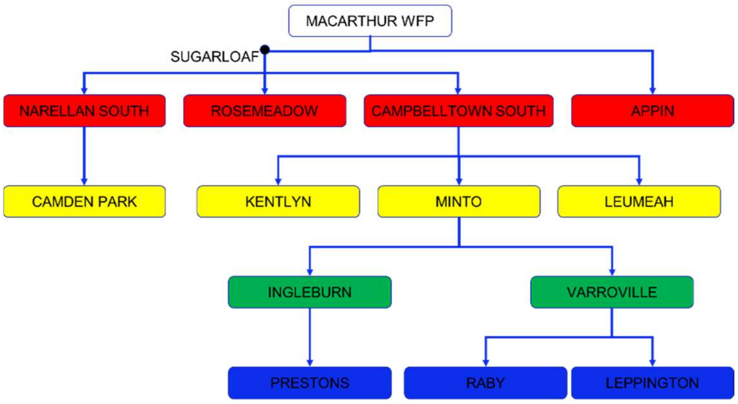


Figure 2: Water flow across the main reservoirs

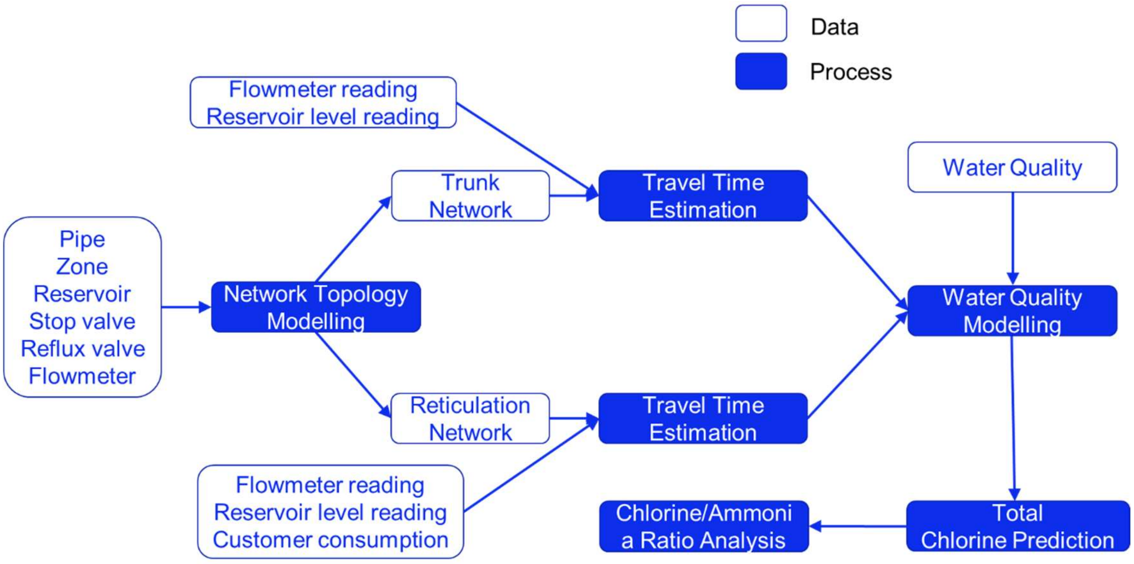


Figure 3: The overall solution diagram

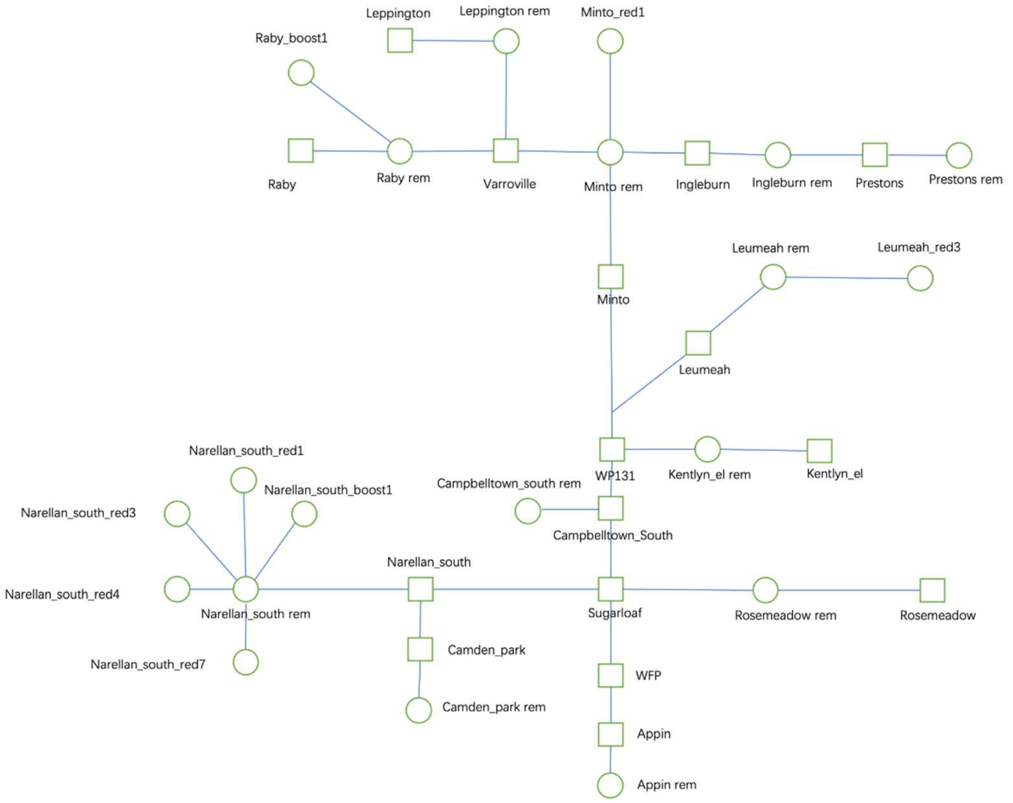
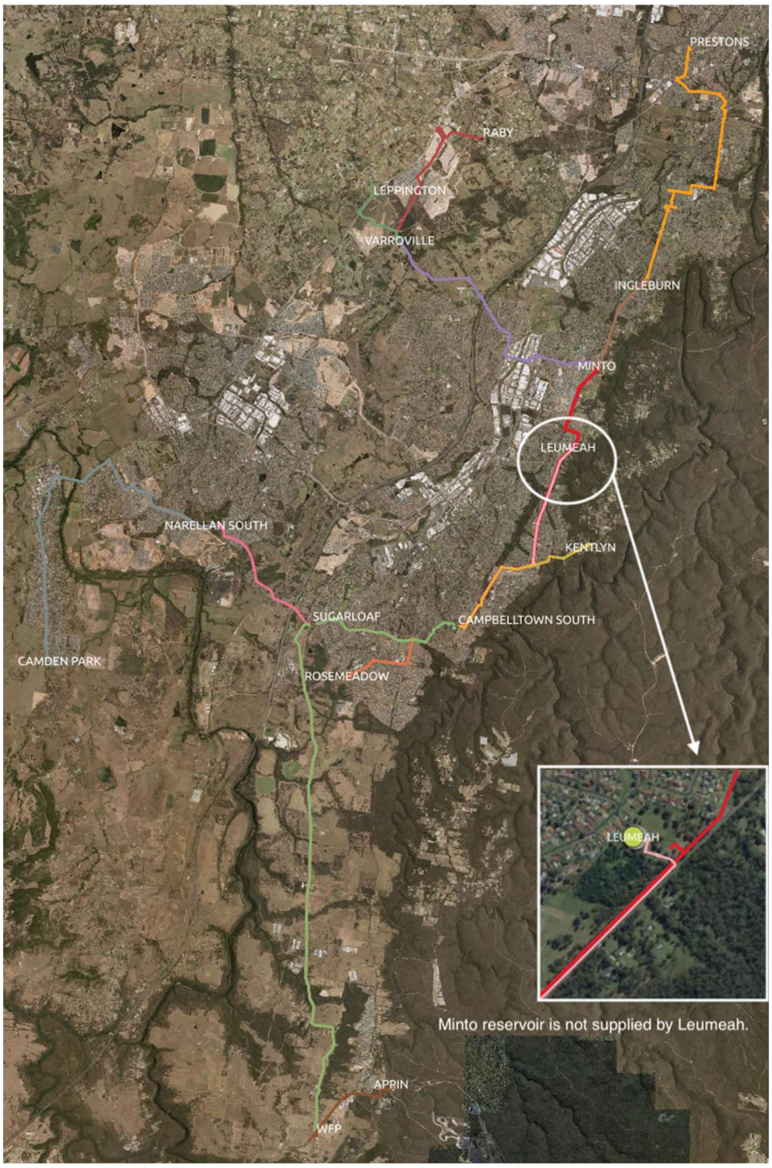


Figure 4: Macroscopic network topology (square: Storage Zone, circle: Flow Zone)



Minto reservoir is not supplied by Leumeah.

Figure 5: The simulated trunk routes between reservoirs based on network topology modelling

Table 1: Estimated water travel time for trunk network

From	To	Travel Time (min)	Travel Time (min) from WFP
WFP	Sugarloaf	298	298
Sugarloaf	Narellan South	145	444
Sugarloaf	Rosemeadow	1339	1638
Sugarloaf	Campbelltown South	162	461
Narellan South	Camden Park	810	1255
Campbelltown South	Leumeah	210	672
Campbelltown South	Kentlyn	475	937
Campbelltown South	Minto	181	643
Minto	Ingleburn	133	777
Minto	Varroville	369	1013
Varroville	Leppington	282	1295
Varroville	Raby	493	1789
Ingleburn	Prestons	236	1013

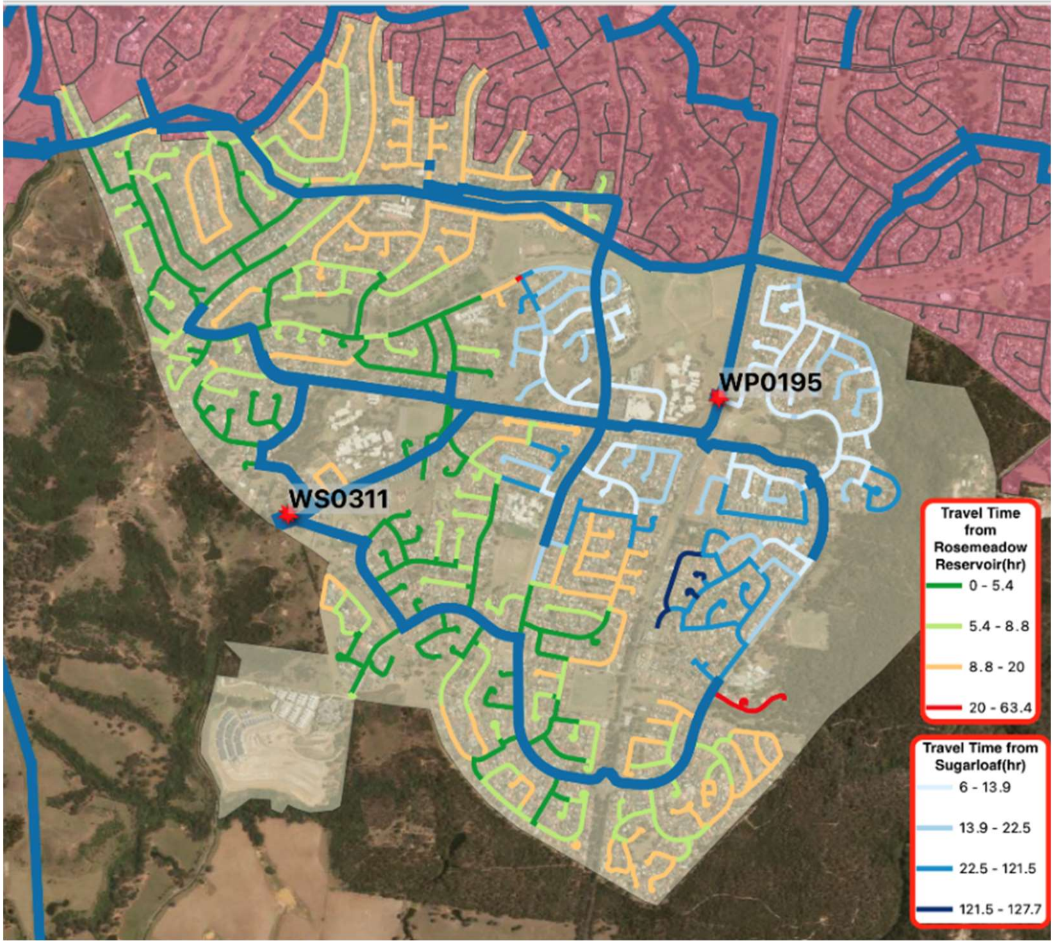


Figure 6: The estimated water travel time for Rosemeadow reticulation network

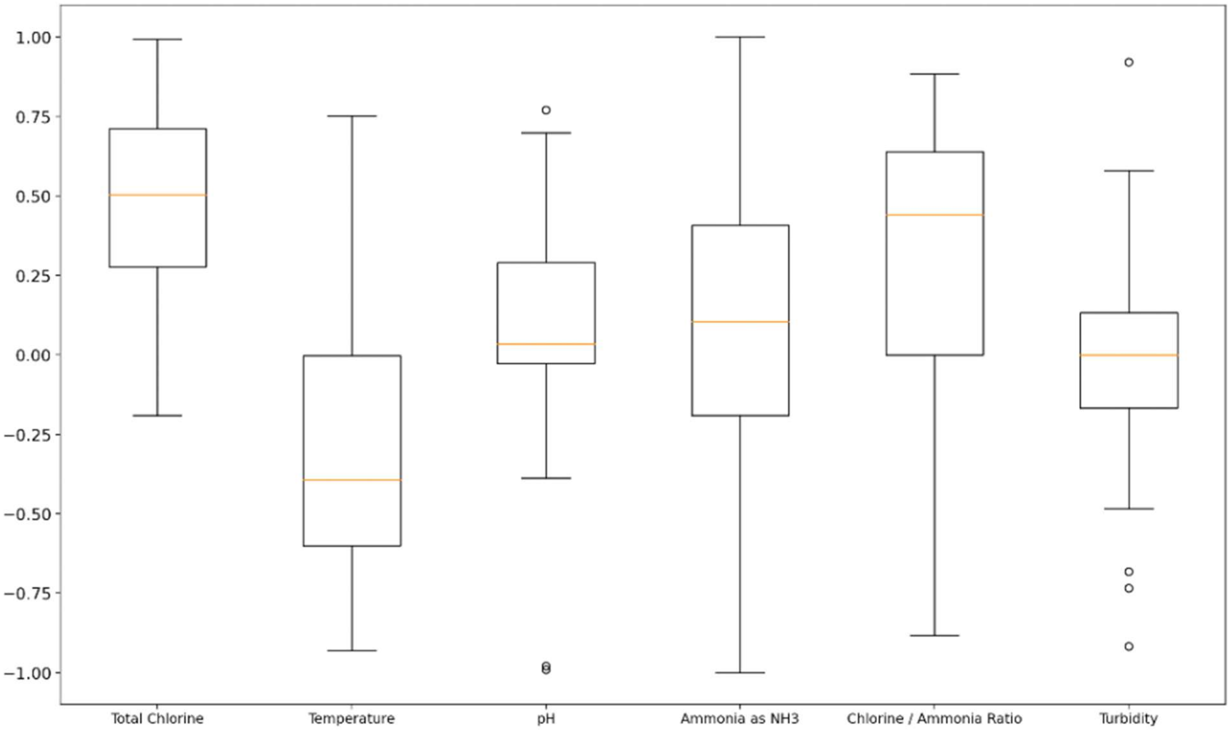
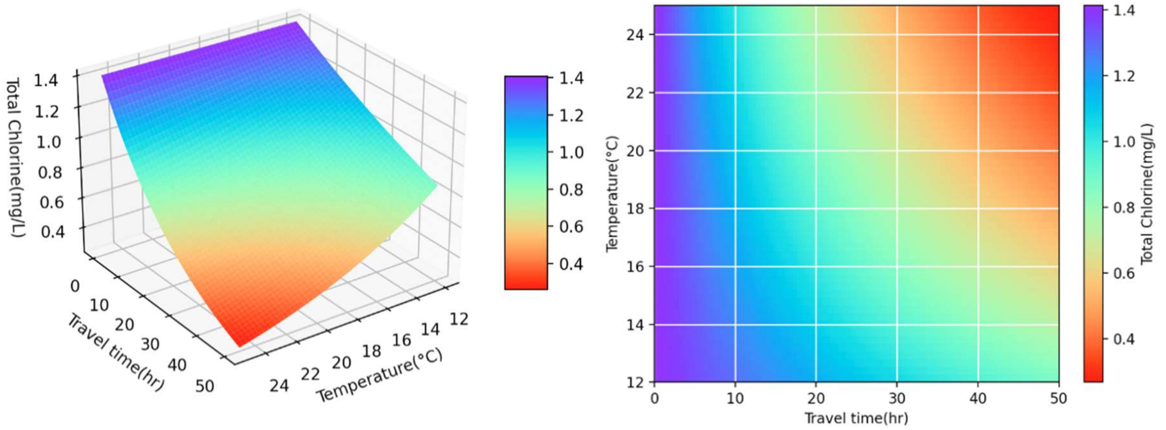
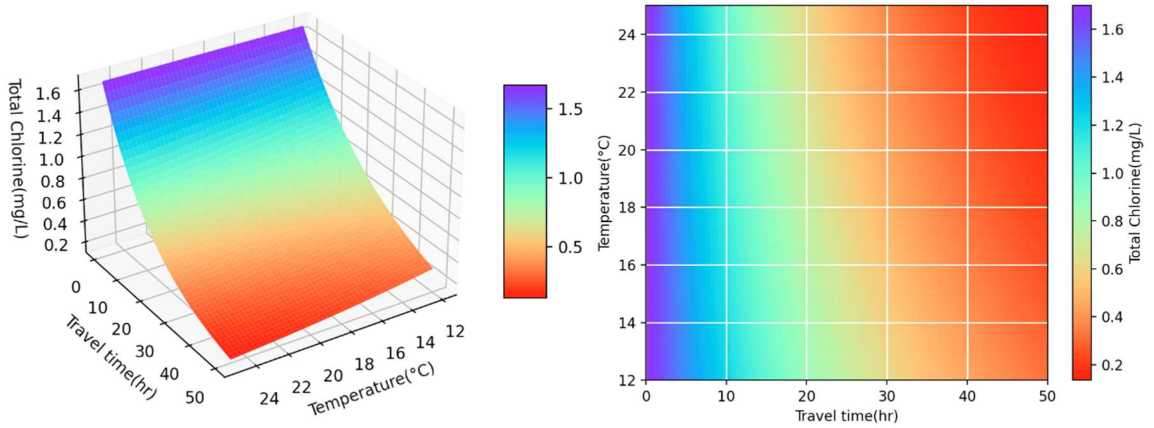


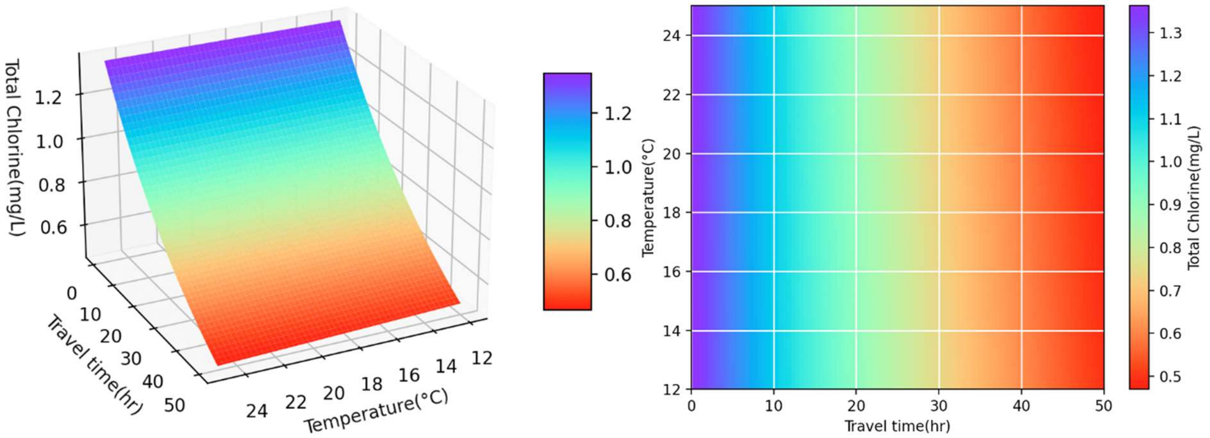
Figure 7: Correlation between the total chlorine at downstream tap sites and a series of measurements at upstream reservoirs



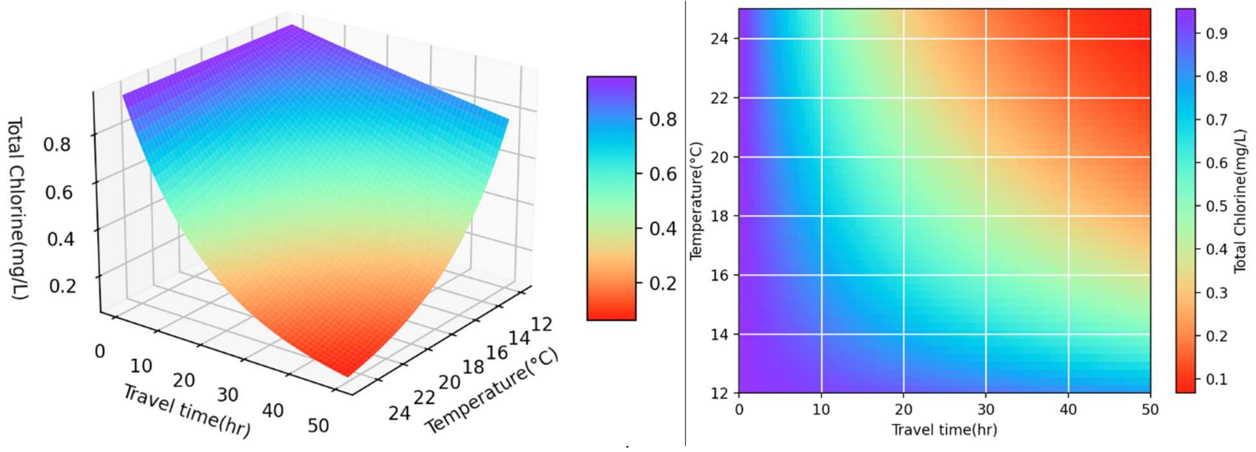
(a) Minto



(b) Appin



(c) Leppington



(d) Kentlyn

Figure 8: Total chlorine prediction models for sample reservoir zones

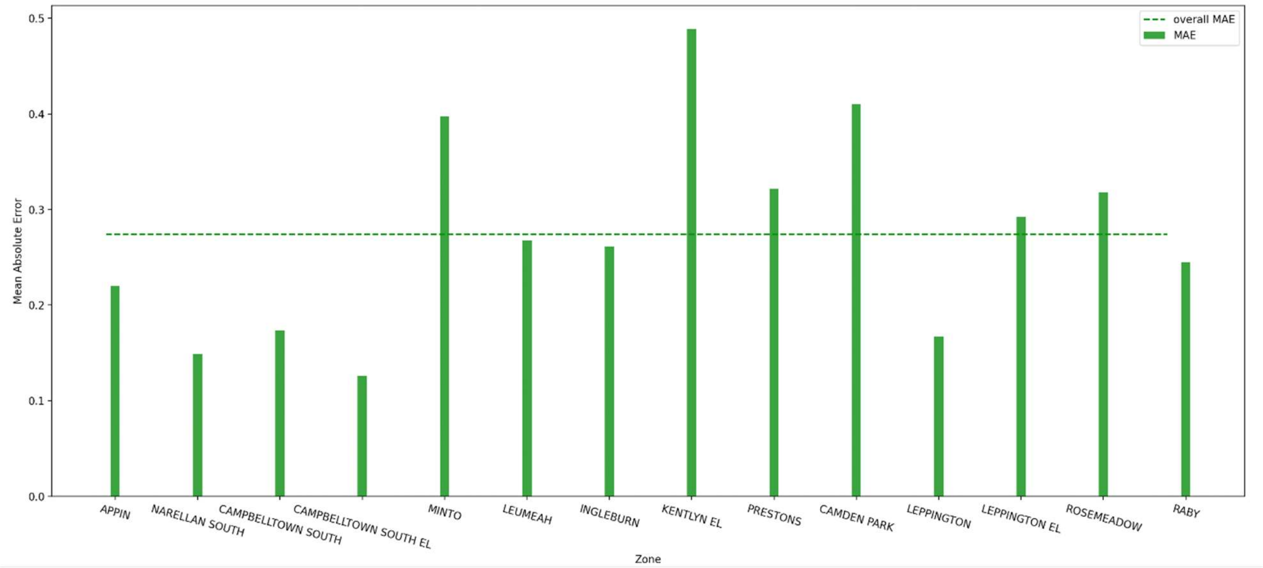
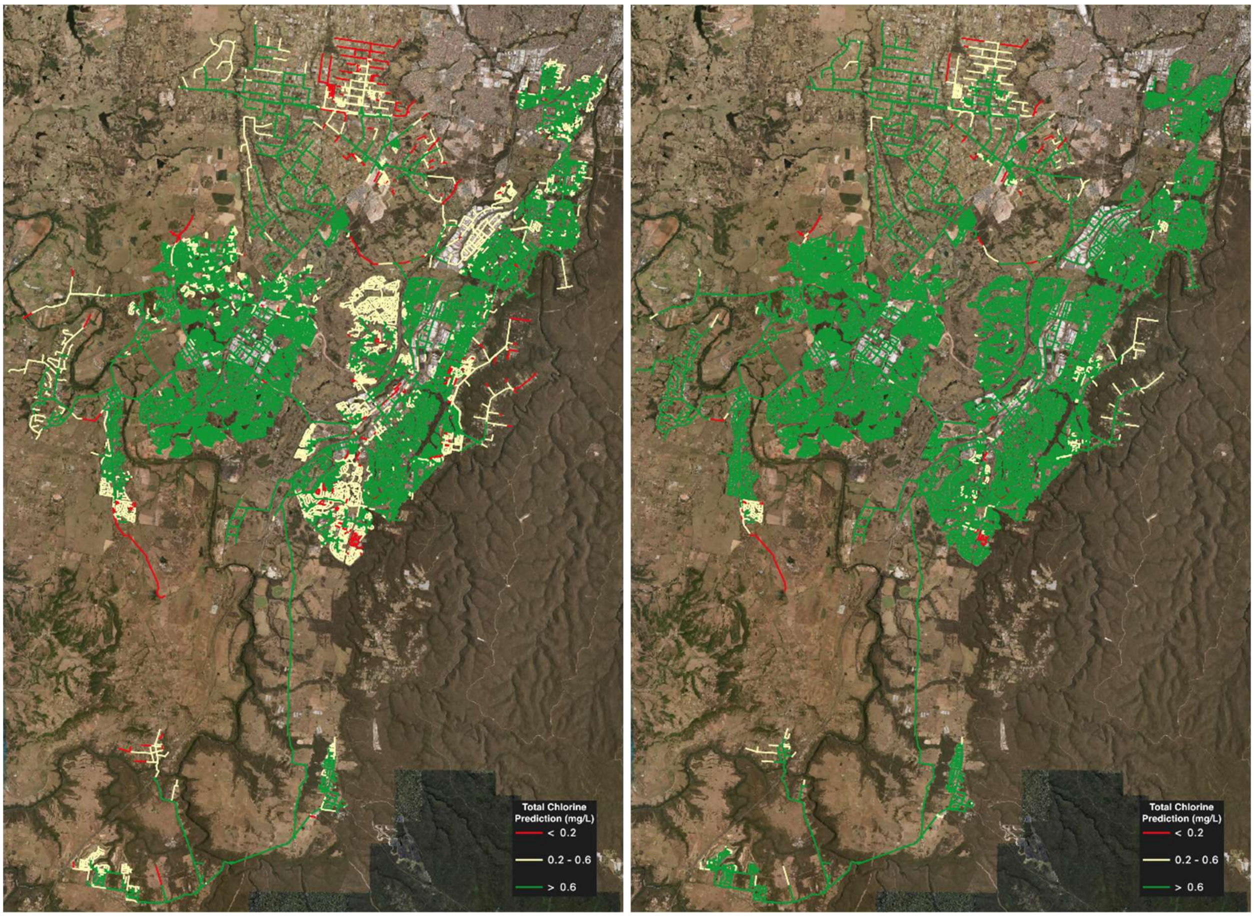


Figure 9: Mean absolute error of predicted total chlorine



(a)

(b)

Figure 10: Predicted total chlorine in (a) summer and (b) winter