WATER QUALITY PREDICTION IN A CHLORAMINATED SYSTEM FOR DROUGHT RESILIENCE

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KEYWORDS

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

ABSTRACT

Drought conditions can deeply impact water supplies and make it more challenging for water quality prediction in chloraminated systems with nitrification. This paper demonstrated the drought resilience options using a data-driven water quality prediction model that was also used to validate the current disinfection regime for the Woronora delivery system in southern Sydney. A water quality prediction model, which has been validated by mobile water quality monitoring analysers to predict the total chlorine with high level of confidence, has been developed. The outcomes of the project can be used to assess the impact of feeding water from the Prospect Water Filtration Plant (WFP) into the Woronora delivery system on total chlorine levels and assess the optimisation of the disinfection regime through operations for drought resilience.

INTRODUCTION

Ensuring the supply of clean and safe drinking water is a key objective for all water utilities. Within chloraminated networks, maintaining total chlorine levels is a key driver for the overall water quality. Sydney Water, Veolia and University of Technology Sydney analytics team have studied the Woronora delivery system and built analytics models for water quality modelling (Peters et al., 2020). Simulation on historical data demonstrates that the models are effective in predicting water quality. A prediction model for water quality has been built to provide quantitative predictions of total chlorine residual for the whole reticulation network downstream of reservoirs, for any target date included in historical records in different supply zones of the system. The developed quantitative model can link the upstream operational decisions and external influences on total chlorine and travel time to assess the impact to customers.

Drought is increasing in frequency and severity due to climate change. It is a complex natural hazard which affects all climates and results in socio-economic impacts including significant changes in water quality. The latest research from Sydney Water reveals in 2019 levels across 11 dams in Greater Sydney were declining faster than they had in decades. In the past two years up until February 2020, levels had declined from a combined capacity of 96% to just under 55%, falling by around 0.4% a week. Sydney was experiencing one of the most severe droughts on record in 2019. Drought conditions were impacting water supplies and there was an urgent need for an effective plan during drought periods to ensure water supply continuity and to deliver safe and secure water to customers.

Motivated by the successful studies on the Woronora delivery system, the developed water quality prediction model will be calibrated and extended to make optimal plans to ensure water supply continuity and the quality of the water supplied during the dry season. By incorporating mobile water quality monitoring analysers, we have refined the model to provide the updates of water quality predictions for the Woronora delivery system, and extended the model to make water quality predictions for the Sutherland supply zone.

The Woronora delivery system (Figure 1) includes 12 reservoir zones and supplies 80 ML of water per day to 210,000 customers in 42 separate pressure zones. Under normal operating conditions, the majority of the water is supplied from Woronora Dam via Woronora WFP, with some water coming from Warragamba Dam via Prospect WFP. If the above change is made, water from Prospect WFP will flow into Sutherland reservoir via Allawah reservoir and then on towards Helensburgh.

In order to investigate the impacts of operations on water quality distribution, the following operation scenarios and test options have been considered:

1. The Woronora delivery system is supplied by both Woronora WFP and Prospect WFP;
2. The Woronora delivery system is only supplied by Prospect WFP;
3. The Woronora delivery system is only supplied by Woronora WFP.

Different operation scenarios are illustrated in Figure 2. Scenario 1 corresponds to normal operating conditions, from which we will derive insights for developing the water quality prediction model for scenario 2. The model will be validated by mobile water quality monitoring analysers and able to predict the total chlorine residual with high level of confidence. The predicted total chlorine for the Woronora delivery system in scenario 2 is shown in Figure 3.

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.

In scenario 2, the water quality data at reservoir level is not available from previous modelling (Peters et al., 2020). Thus, to predict water quality at pipe level in this scenario, the water quality at reservoir level needs to be modelled first. Based on the insights derived from the current Woronora delivery system in practice, this section describes water quality prediction model development at reservoir level for Sutherland supply zone. Then water quality prediction at pipe level is performed using the similar methodology as presented by Peters et al., 2020.

In the existing Woronora delivery system, represented as scenario 1, total chlorine is measured at reservoirs at certain time intervals. Based on the data collected from November 2017 to January 2020, the total chlorine measured at 10 reservoir sites including Heathcote, Helensburgh, Heathcote Elevated, Sutherland, Lucas Heights, Loftus, Hargrave Heights, Menai, Stanwell Park, and Engadine were further analysed. More specifically, the mean and standard deviation values of total chlorine at each of the reservoirs during the observation period are shown in Figure 4 and Figure 5. The difference between the two figures lies in how the 10 reservoirs were arranged from left to right. In Figure 4 they were sorted based on the total time which is a summation of travel time and detention time. While in Figure 5, they were arranged according to their travel time as estimated by Peters et al., 2020.

As can be seen, the mean and median total chlorine values at each reservoir are very similar. There seems no obvious relationship between total chlorine and total time at the reservoirs as indicated in Figure 4. However, more insights could be derived from Figure 5. When travel time is short, the standard deviation value tends to be small. However, at Lucas Heights and Sutherland reservoirs which correspond to long travel time, the variation of total chlorine is quite significant. Furthermore, there is a decreasing trend for total chlorine values with travel time increasing. This accords with the well-established total chlorine decay theory as presented by Peters et al., 2020. Based on this understanding, multiple exponential decay models were further trained using the available data from Woronora supply zone and plotted in Figure 5. Specifically, total chlorine, ammonia, and chlorine/ammonia ratio were considered as decay dependent variables respectively. Furthermore, in the cases of ammonia-based and chlorine/ammonia-based modelling, we have considered the situations whether the data collected by the ammonia mobile analyser would be used for model fitting. These models could be employed for total chlorine estimation at reservoir level if the total chlorine at the upstream water source is known and the travel time to a specific reservoir is available. It should be noted that lower total chlorine residual will result in the quicker onset of nitrification generally which in turn will cause nonlinear drop in total chlorine. Such nitrification impacts on total chlorine are very complex and were not considered in our modelling.

RESULTS

Prediction Results at Reservoir Level

Based on the trained models as described in the previous section, the predicted total chlorine at Woronora WFP and 10 reservoirs are plotted in Figure 6. The mean values of historical measurements are shown as ground truth. It is noticed that the proposed models tend to under predict total chlorine for Engadine reservoir compared with other reservoirs and over predict total chlorine for Heathcote and Heathcote elevated reservoirs, which will be investigated further in the future. Moreover, mean absolute error was calculated for the purpose of quantitative evaluation, which is shown in Figure 7. As shown, chlorine or ammonia-based modelling led to similar mean absolute error of around 0.18. Prediction using chlorine/ammonia ratio could result in a reduced mean absolute error of about 0.13. Furthermore, better mean absolute error could be achieved when ammonia mobile analyser data was incorporated into the modelling. As such, chlorine/ammonia-based modelling with ammonia mobile analyser data considered will be used for the following analysis.

We then extend the water quality model to scenario 2 for reservoir level prediction. The travel time for each reservoir from Sutherland reservoir is shown in Table 1. Applying these travel times to the trained model, we can obtain the prediction value of total chlorine at each reservoir with Sutherland being the supply, which is presented in Table 1 as well.

Prediction Results at Pipe Level

By the leverage of the predicted water quality at reservoir level, updated 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 of the last three years while the winter one is calculated across May to July. The pipe level prediction results are shown in Figure 3.

CONCLUSION

A secure and safe supply of drinking water is fundamental to public health. Ensuring the continuous supply of high-quality drinking water is a critical requirement for water supply network management. Maintaining water quality through the water delivery system to the point of consumption at the customers tap is one of the most challenging tasks faced by water utilities especially during drought periods, taking into consideration the components of the delivery system (e.g., pipe materials, tanks, valves) and other operational information (e.g., flow, demand).

This paper has proposed a data-driven solution to predict water quality for the Woronora delivery system for drought resilience. The developed water quality prediction model has been validated by mobile water quality monitoring analysers and is able to predict the total chlorine with high level of confidence. This work has established a successful initiative to improve the overall water supply management for the entire Woronora delivery system. Key outcomes of the work include:

- Successful options of total chlorine management for drought resilience;
- Innovative travel time estimation model together with the learning of the system was key success in predicting and validating the total chlorine;
- Ability to develop an operationally validated model that is trained within the system achieved drought resilience options to plan the supply by the Prospect system.

REFERENCES

Peters, A., Liang, B., Tian, H., Li, Z., Doolan, C., Vitanage, D., Norris, H., Simpson, K., Wang, Y., Chen, F. 2020. Data-driven water quality prediction in chloraminated systems. Water e-Journal, 5(4), 1-19

Table 1: Estimated travel time and predicted water quality at reservoir level for scenario 2

Reservoir	Travel Time from Sutherland (min)	Predicted Total Chlorine (mg/L)
Sutherland	0	1.011
Lucas Heights	446	0.946
Menai	616	0.922
Engadine	620	0.921
Loftus	716	0.909
Heathcote	750	0.904
Heathcote Elevated	768	0.901
Helensburgh	5043	0.477
Hargrave Heights	5462	0.448
Stanwell Park	5472	0.447

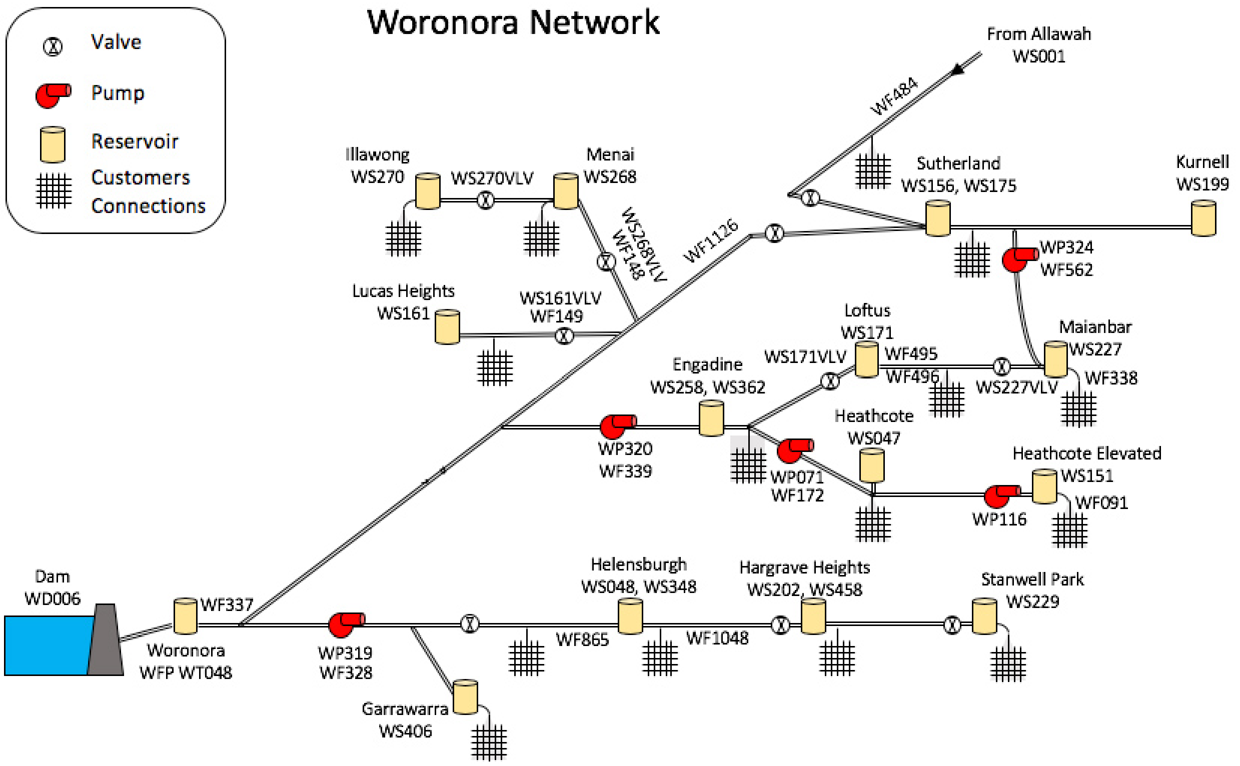
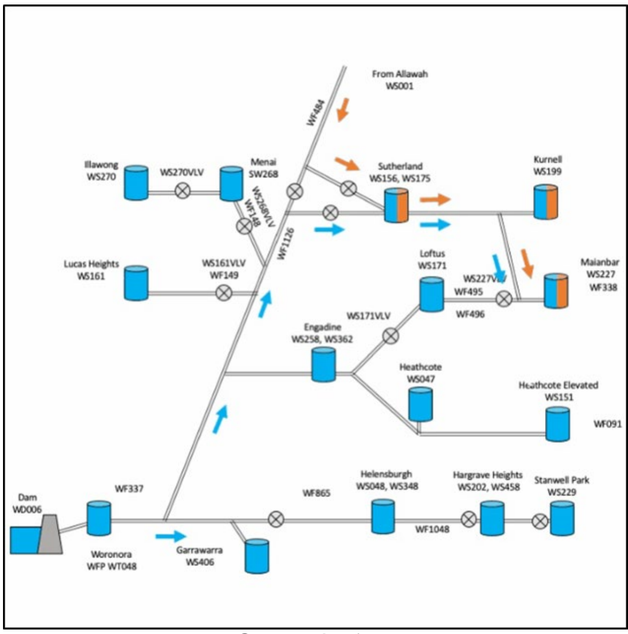
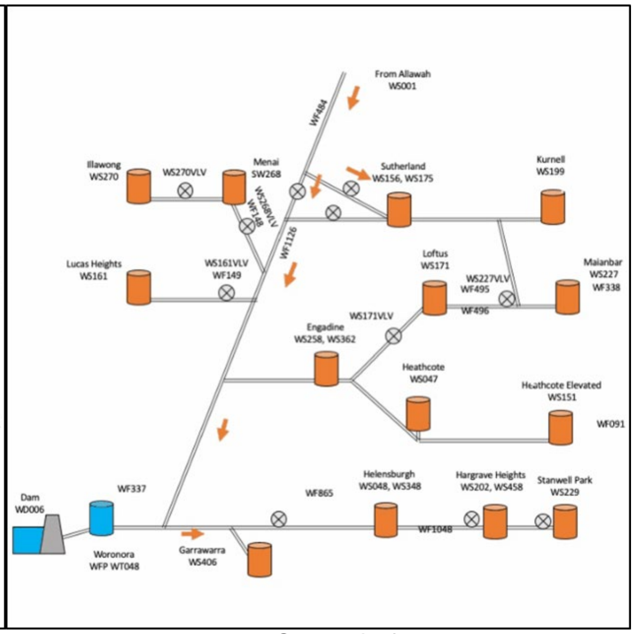


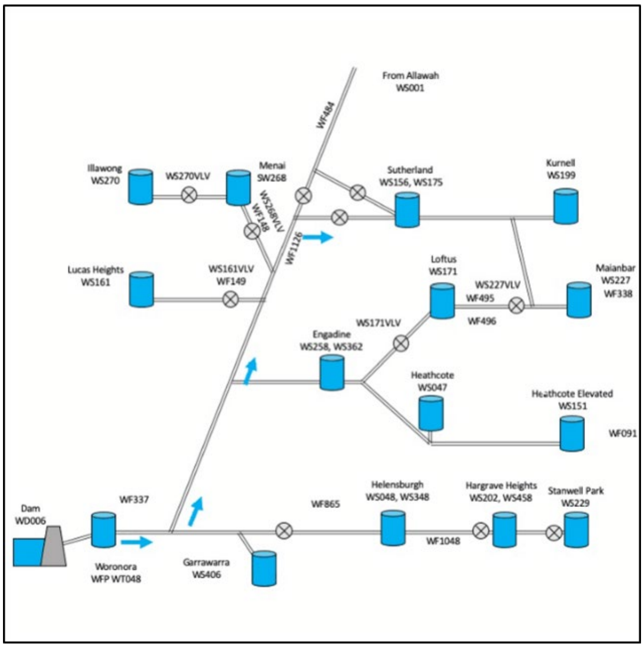
Figure 1: Woronora delivery system



Scenario 1

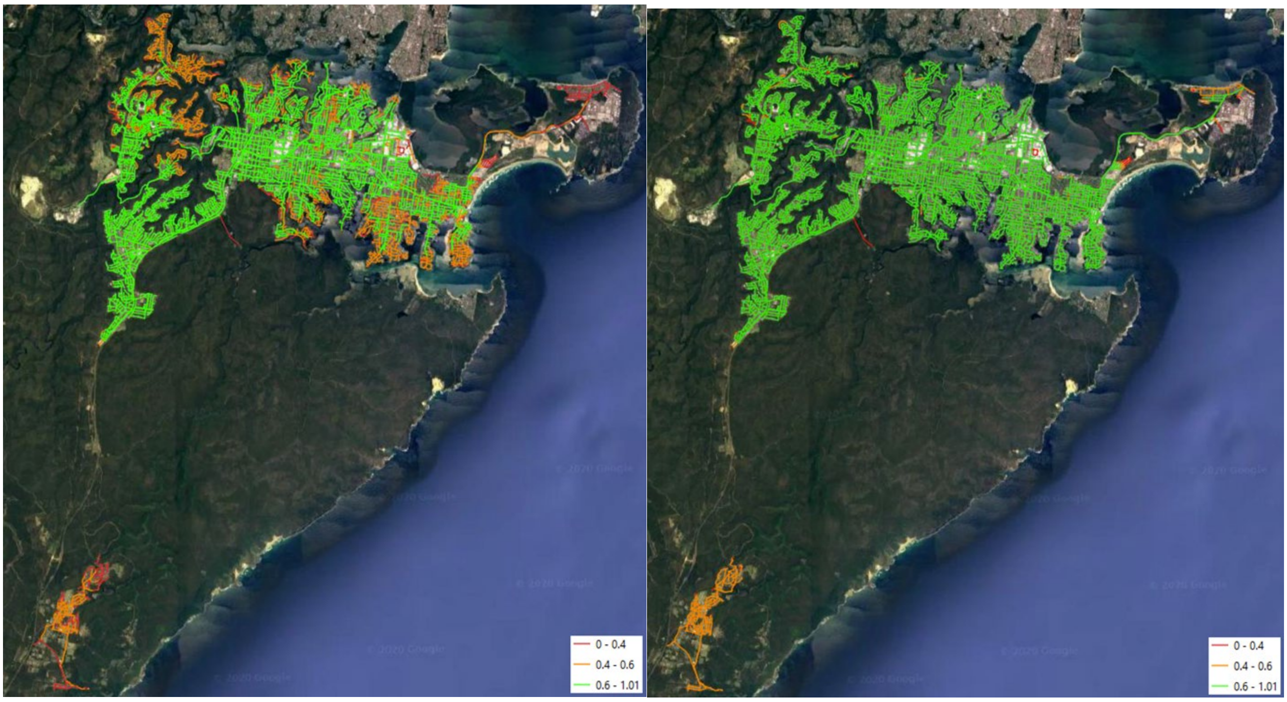


Scenario 2



Scenario 3

Figure 2: Investigated operation scenarios



(a) *(b)*

Figure 3: Predicted total chlorine in (a) Summer and (b) Winter for scenario 2

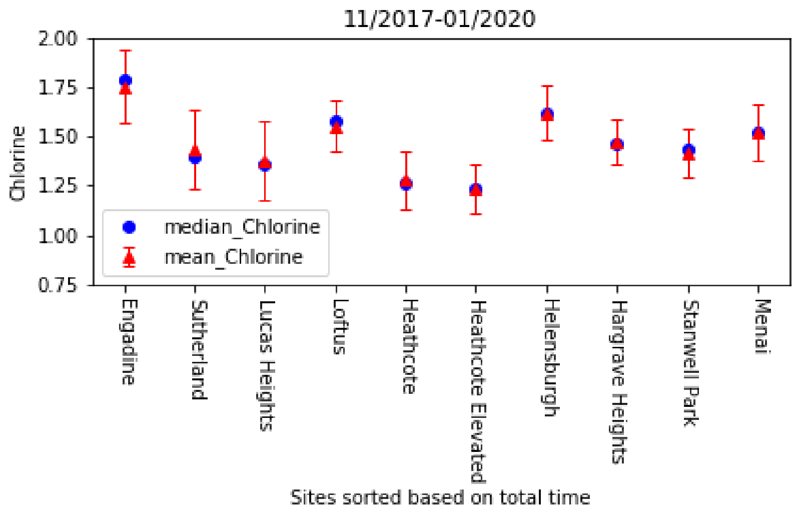


Figure 4: Mean, standard deviation, and median values of total chlorine at 10 reservoirs during 11/2017~01/2020 in scenario 1 (the reservoirs were arranged from left to right based on their travel time plus detention time)

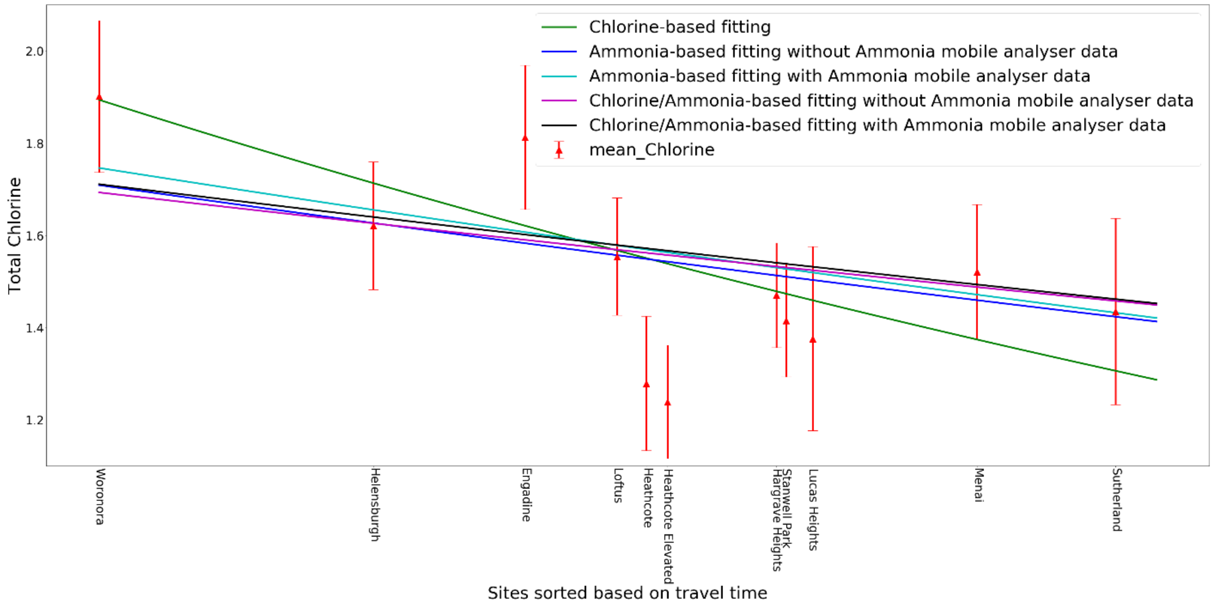


Figure 5: Mean, standard deviation, and fitted models of total chlorine at Woronora WFP and reservoirs during 11/2017~01/2020 in scenario 1 (the reservoirs were arranged from left to right based on their travel time)

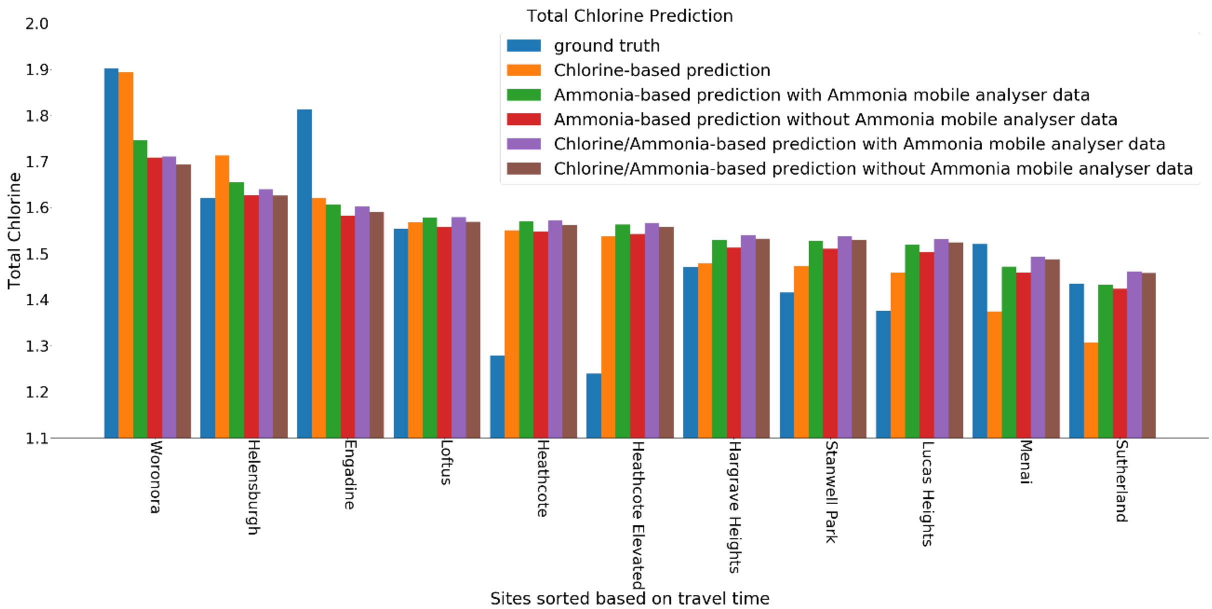


Figure 6: Predicted total chlorine at Woronora WFP and reservoirs using different models in scenario 1

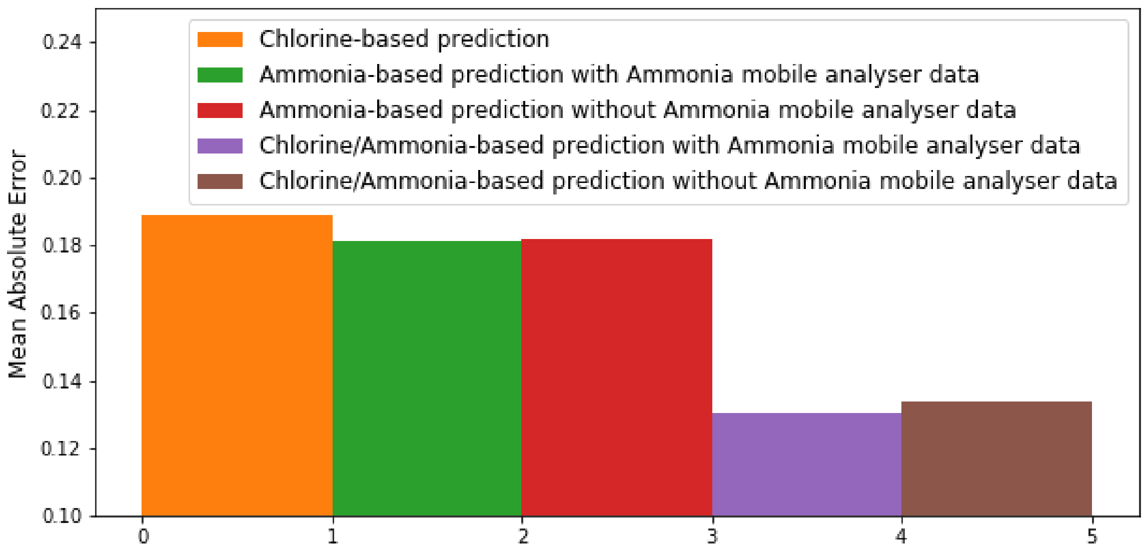


Figure 7: Mean absolute error of predicted total chlorine in scenario 1