Residual Chlorine Decay Simulation in Water Distribution System

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Abstract

Controlling free residual chlorine properly is definitely important to ensure meeting regulatory requirements and satisfying customer needs. Residual chlorine decay simulation development in water distribution system of Osaka Water is in progress.

This paper describes a case study of free chlorine decay simulation with EPANET2 extended period water quality simulation algorithm using data collected in field sampling study. First-order bulk decay coefficients and its relations with water temperature are investigated through bottle tests. Zero-order pipe wall reaction coefficients for certain area at specific water temperature are determined by trial-error method using observed data.

Keywords

Residual Chlorine, Distribution System, Extended Period Simulation, Pipe Wall Reaction, Reaction Rate Coefficients, EPANET

1. Introduction

Osaka Water installed advanced water treatment facilities with ozonation and granular activated carbon treatment processes on existing coagulation sedimentation and rapid sand filtration facilities. On March 2000, Osaka Water started to supply drinking water with advanced treatment throughout the city area. With the advanced treatment processes, organic matters in finished water had decreased drastically, free chlorine concentration could be reduced at purification plant after March 2000.

On the other hand, chlorine is injected at purification plants and newly installed 2 distribution plants to destroy pathogenic organisms and eliminate and prevent waterborne diseases, meet regulatory requirement (0.1 mg/*l* and over at water tap)*, therefore, there are regional imbalance of free residual chlorine concentration between hydraulically near area and far area from purification plants.

*Note: Regulation of free chlorine concentration in Japan

(Enforcement Regulation of Waterworks Law)

Disinfection should be done with chlorination to keep free residual chlorine at least 0.1 mg/*l* (0.4 mg/*l* and over in chloramines) at water tap. In case of being at risk of pathogenic organisms contamination, disinfection should be done to keep free residual chlorine at least 0.2 mg/*l* (1.5 mg/*l* and over in chloramines).

(Water Quality Standard for Drinking Water 2003)

Complementary item suggested to be preserved (not mandatory): Residual chlorine: 1 mg/*l* or less

To supply safer and higher quality drinking water and solve imbalance problem, establishment of more strict free chlorine concentration control in water distribution system with free chlorine decay simulation is currently under development. A field sampling study was done at Sakishima district in Osaka city. USEPA's network simulation program embedded in MIKE URBAN Water Distribution, excellent GIS based software by DHI software, was used to perform extended period water quality simulation. And comparison of predicted and observed free chlorine concentrations was made.

2. Methods

2-1. Field studies in Sakishima district

The location of Sakishima district and routes from purification plant to the district are shown in Fig.1. Raw water from River Yodo is treated at Niwakubo purification plant and is transmitted to Tatsumi distribution plant with pumps. Water from Tatsumi distribution plant reservoirs is pumped up to Tatsumi water supply area and Sakishima distribution plant. Then water from Sakishima distribution plant reservoirs is pumped up and distributed to Sakishima supply area.

It is suitable for modeling because the only water source is Sakishima water distribution plant in Sakishima supply area, and then the area was chosen in field studies. A schematic diagram of Sakishima network model is shown in Fig.2. Pipes of all diameters are considered in modeling. Hazen-Williams formula is used as a head loss equation.

Most pipes in Sakishima district were buried in 1970-1980 as the land reclamation. All pipes are lined with mortar.

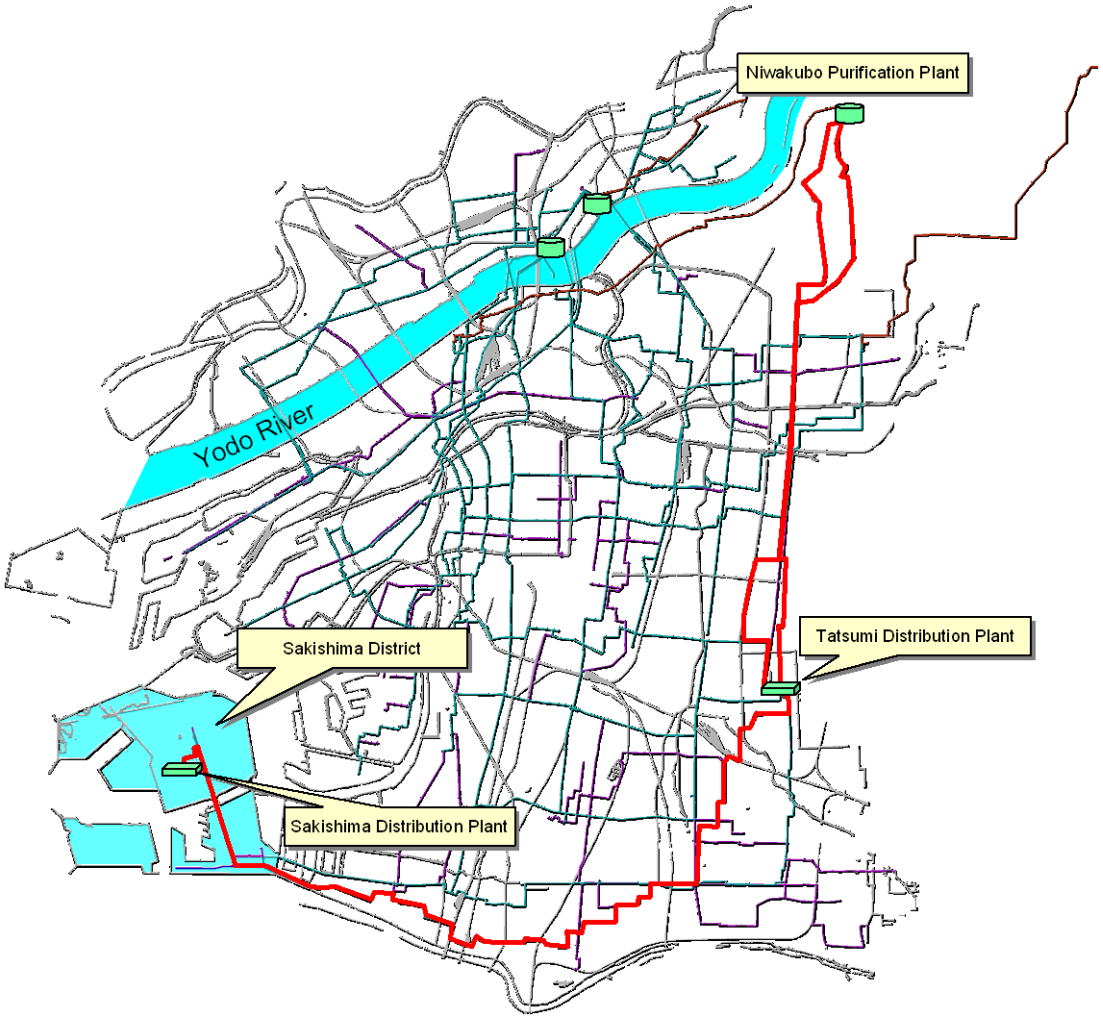

Fig.1. Location of Sakishima district and route from a water distribution plant

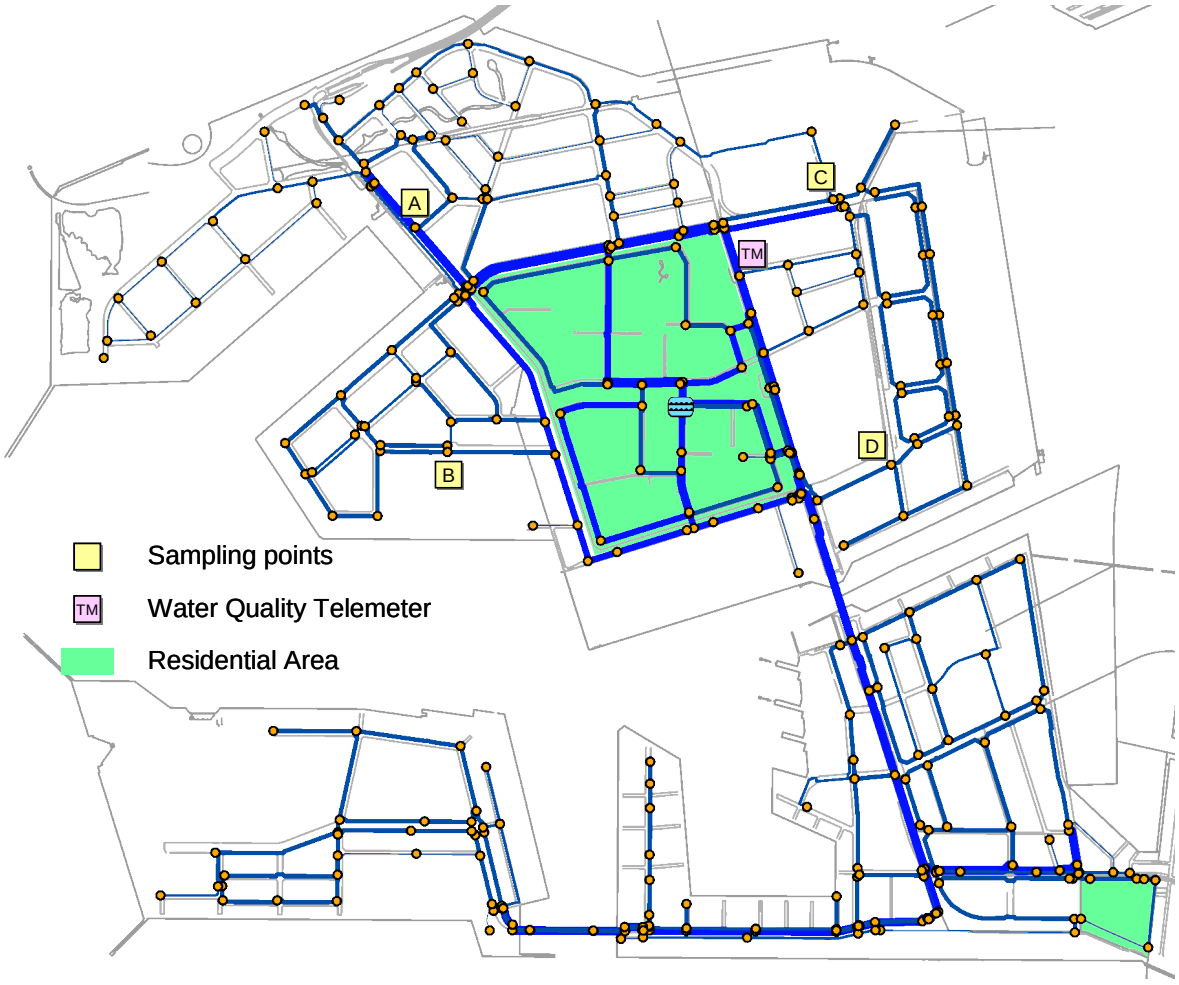

Fig.2. Schematic diagram of Sakishima network model and sampling points

Free chlorine concentration control in Sakishima supply area

Chlorine is injected at the end of treatment processes in Niwakubo purification plant, and then additional chlorine is injected at the inflow of Sakishima distribution plant reservoir.

Injection of chlorine at the purification plant is controlled to keep predefined concentration considering with concentration measured at the city area with water quality telemeters.

Free chlorine concentration at the Sakishima supply area is measured with Nanko-higashi water quality telemeter.

2-2. Field sampling studies

Data were collected from field sampling studies that were performed July 5, 2005 (Tuesday). Sampling points (hydrants) are showed in Fig.2. Tab.1 shows the results.

Tab.1 Results of field sampling studies

Sampling Points	Free Chlorine Concentration (mg/*l*)	Water Temperature (^{o}C)	pH	Sampling Time
A	0.42	26.2	7.54	09:33
B	0.30	25.9	7.69	09:59
C	0.35	25.9	7.82	11:29
D	0.46	26.4	7.55	09:40

Tab.2 shows measured data of water quality telemeters, Sakishima outflow and Nanko-higashi. Fig.3 shows inflow and outflow of Sakishima distribution plant and water volume stored in the reservoir.

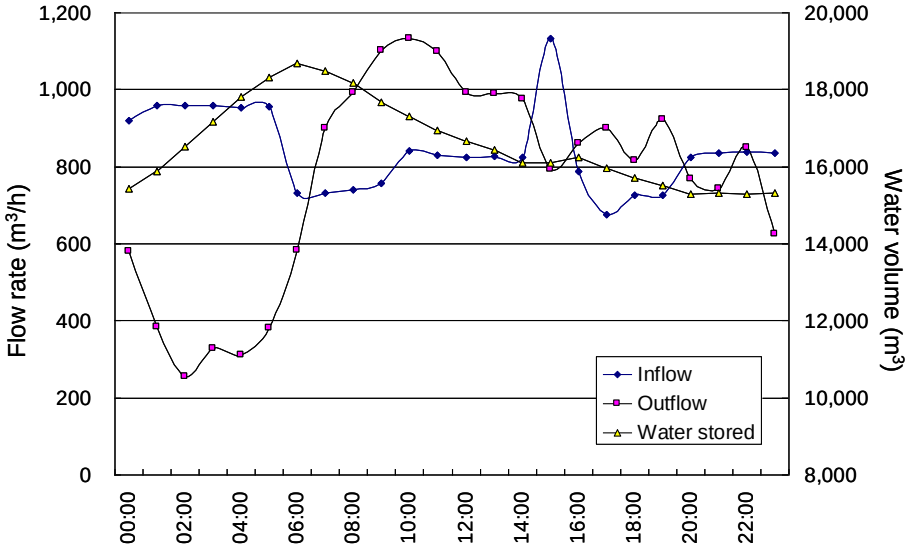

Fig.3 Inflow and outflow of Sakishima distribution plant and stored water volume in the reservoir

Tab.2 Water quality telemeter data (mean)

Time	Sakishima Outflow	Nanko-higashi		
	Free Chlorine Concentration (mg/*l*)	Free Chlorine Concentration (mg/*l*)	Water Temperature (^{o}C)	pH
00:00-01:00	0.48	0.44	26.2	7.6
01:00-02:00	0.48	0.44	26.2	7.6
02:00-03:00	0.48	0.44	26.1	7.6
03:00-04:00	0.48	0.44	26.1	7.6
04:00-05:00	0.48	0.44	26.1	7.6
05:00-06:00	0.48	0.43	26.1	7.7
06:00-07:00	0.48	0.43	26.0	7.7
07:00-08:00	0.48	0.43	26.1	7.7
08:00-09:00	0.48	0.45	26.3	7.6
09:00-10:00	0.48	0.46	26.5	7.6
10:00-11:00	0.48	0.46	26.7	7.6
11:00-12:00	0.48	0.46	26.8	7.6
12:00-13:00	0.48	0.45	26.9	7.6
13:00-14:00	0.48	0.45	26.9	7.6
14:00-15:00	0.48	0.45	26.9	7.6
15:00-16:00	0.47	0.45	26.8	7.6
16:00-17:00	0.47	0.45	26.7	7.6
17:00-18:00	0.47	0.44	26.5	7.6
18:00-19:00	0.47	0.44	26.3	7.6
19:00-20:00	0.47	0.44	26.3	7.6
20:00-21:00	0.48	0.44	26.2	7.6
21:00-22:00	0.49	0.45	26.1	7.6
22:00-23:00	0.50	0.46	25.9	7.6
23:00-24:00	0.50	0.47	25.8	7.6

2-3. Chlorine decay kinetics

Based on past studies[1) 2)], first-order decay model was used as reaction kinetic model for chlorine in the bulk liquid, and zero-order decay model was used as wall reaction kinetic model.

$$\frac{dC}{dt} = k_b C + \frac{4}{d} k_w$$

C: Free chlorine concentration (mg/*l*)

k_b: First-order bulk decay coefficient (1/day)

k_w: Zero-order wall reaction decay coefficient (mg/m^2/day)

d: Pipe diameter (mm)

Bulk decay coefficient k_b

Relationship between k_b and water temperature was studied by analyzing the results of bottle tests that were

conducted on treated water at Niwakubo purification plant[3].

Colorimetrical tubes (25m*l*) stoppered tightly with treated water were stood stilly in thermostatic chamber at specified temperature in light shielding condition. And the initial concentration was measured. After predefined period, each sample was selected and the free chlorine concentration was measured. Fig.4. shows results of experiments.

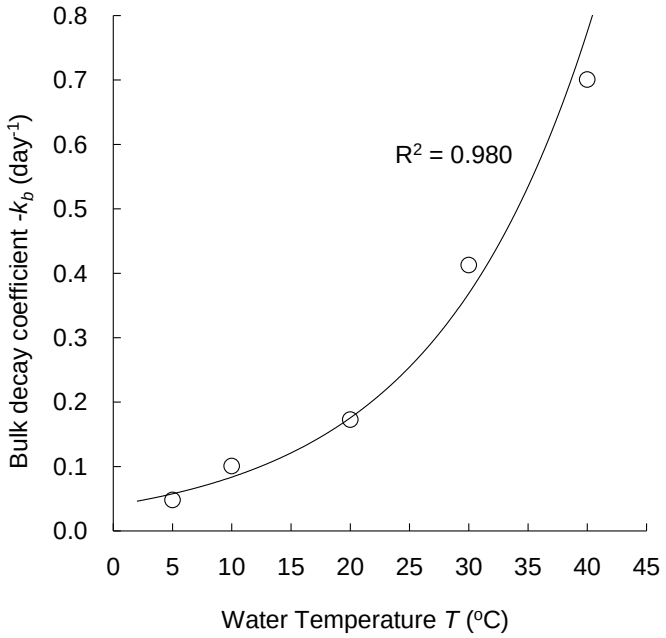

Fig.3 Relationship between bulk decay coefficient and water temperature

$$k_b = -0.0398 \exp(0.0742T)$$

k_b : Bulk decay coefficient in Niwakubo purification plant treated water (day^{-1})

T : Water temperature (°C)

Wall reaction decay coefficient k_w

It might be considered wall reaction decay depends on actual pipe wall condition and lining material. Then k_w was set as predicted concentration fit together observed concentration by trail and error, assuming same k_w for all pipes in Sakishima district, all pipes in the area were lined with mortar and most of pipes were buried in 1970-1980. The k_w might be used in condition with 26 °C water temperature at Sakishima district.

2-4. Pipe network analysis

Pipe network analysis was performed with MIKE URBAN Water Distribution by DHI, which is embedded with USEPA's EPANET2 as the calculation engine. To simulate time series variation of free chlorine concentration, extended period water quality analysis was done. Sakishima district consists of residential

area and others, and time factor curves for each area might be different significantly.

Time factor curves

A time factor curves for non-residential area was made from a curve for residential area and measured time variation of Sakishima distribution plant outflow. Time factor curves used in the calculation are showed in Fig.5.

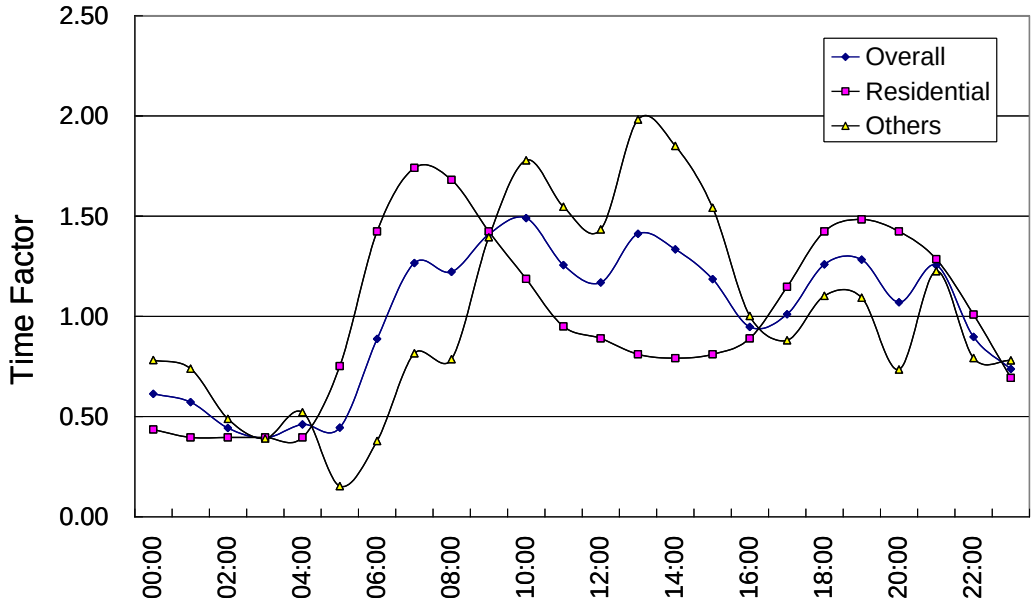

Fig.5 Time factor curves

3. Results and discussion

3-1. Results

Extended period water quality analysis was performed and the k_w was determined (k_w = -4.0 (mg/m^2/day)) in order that the predicted concentration fit well together the observed concentration. Comparison of predicted and observed free chlorine concentration is shown in Fig.6. Predicted concentration for sampling point A, B, D are as of 10:00, concentration for sampling point C is as of 11:00. Then time series variation of predicted free chlorine concentration for each sampling points and measured concentration of outflow from Sakishima reservoir are shown in Fig.7.

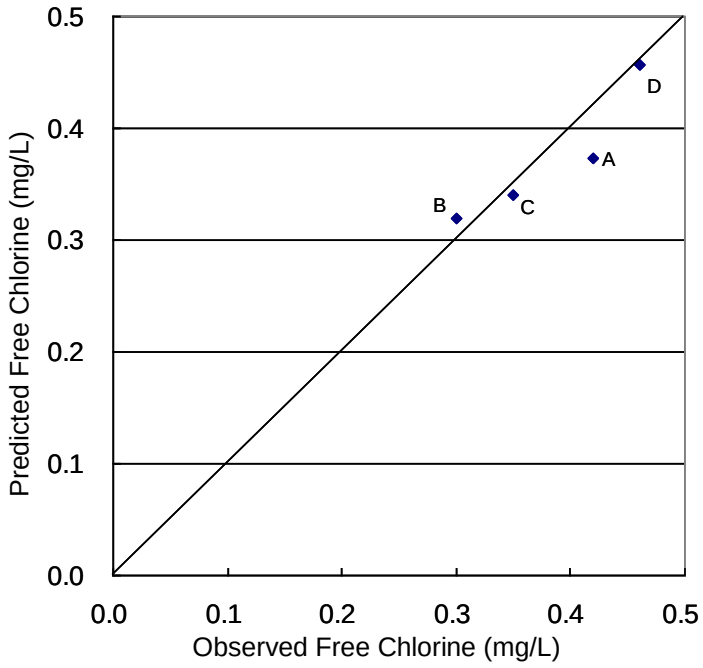

Fig.6 Comparison of predicted and observed free chlorine concentrations

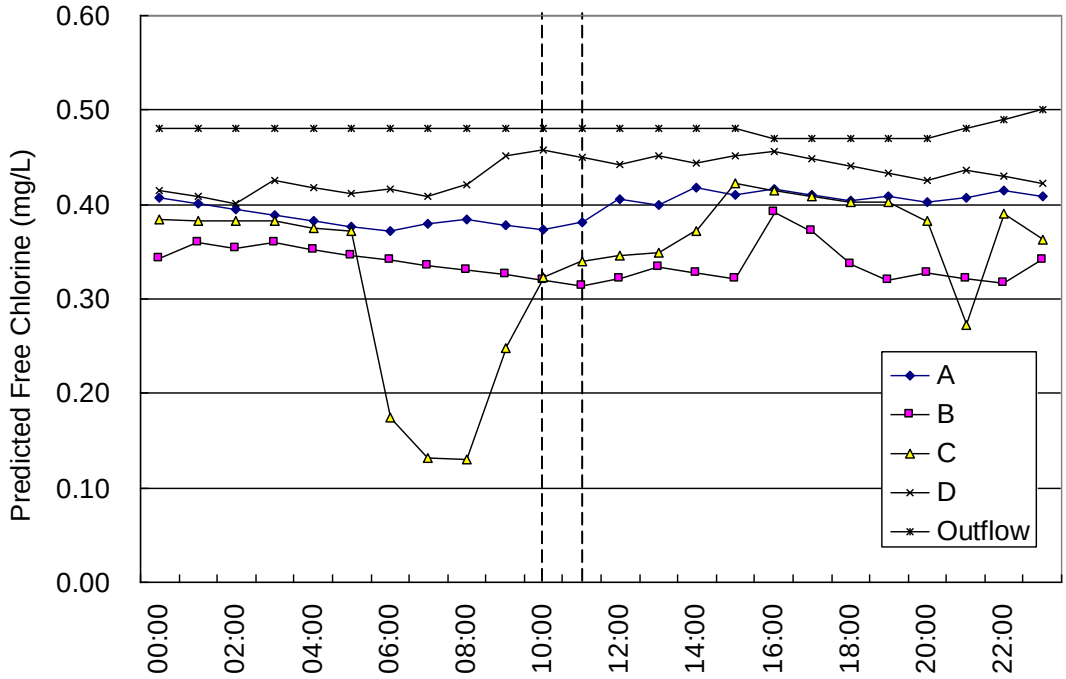

Fig.7 Time series variation of predicted concentrations and measured concentration of outflow

3-2. Discussion

Free chlorine concentration in Sakishima district can be predicted about equal to observed values with wall reaction decay coefficient k_w set by trial error, under condition of 26 ^oC water temperature. Predicted concentration can vary over time with EPANET2 extended period water quality analysis.

To see time series variations of predicted concentrations, they are relatively stable in sampling points A, B and D, it shows large change in sampling point C. This indicates water age at sampling point C can change in time series drastically, to consider that same wall reaction decay coefficient k_w were set to all pipes.

In past study[5], flow mixing and time series variation could not be modeled and calculated, single pipeline was assumed and water age was calculated, then free chlorine decay was simulated. With EPANET2 extended period water quality analysis, detailed prediction can be done considering flow mixing and time series variation.

It might be considered that obtained k_w in this case study can apply pipe aged 25-35 years with mortar lining under approximately 26 ^oC water temperature. On the other hand, k_w might be known for different age and lining material by field studies in order to conduct free chlorine concentration simulation in the other city area. Past study[2] shows that the wall reaction decay coefficients can be inversely proportional to pipe roughness coefficients (Hazen-Williams C-factors). In this case study, same Hazen-Williams C-factor and wall reaction decay coefficient k_w can be assumed because all pipe in Sakishima district are buried in same period and have same lining material. Modeling in the other city area, different C-factors and wall reaction decay coefficients should be set depending on pipe roughness.

As for water temperature, to make a prediction under different condition from 26 ^oC, it should be conducted statistical analyses of the relationship between the k_w and water temperature.

As for the bulk decay coefficient k_b, relationship between k_b and water temperature was obtained for Niwakubo purification plant treated water. It might be applied for treated water from the other treatment plants considering water quality of treated water from these purification plants that have same water source, River Yodo, and same water treatment processes.

4. Conclusions

With EPANET2 extended period water quality analysis, time series free chlorine concentration simulation can be conducted in Sakishima district under condition of 26 ^oC water temperature (in summertime).

To apply simulation method for the other city area, future studies are listed below;

- -Field study to obtain wall reaction decay coefficient k_w for epoxy powder coating lining pipes
- -Field study to obtain wall reaction decay coefficient k_w for aged pipes without lining
- -Field study to obtain relationship between wall reaction decay coefficient k_w and water temperature
- -Field study to obtain Hazen-Williams C-factors for aged pipes considering lining materials

-Field study to observe time variation of free chlorine concentration at point the concentration change predicted large

With these studies, it is expected to construct relationship between wall reaction coefficients and water temperature, prediction method for wall reaction coefficients and C-factors with pipe age and pipe lining material obtained from GIS database could be predicted.
To contribute to implementation of strict chlorine concentration control, free chlorine concentration simulation in distribution network for all city area would be established in near future.

5. Acknowledgement

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6. References

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