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Operational And Water Quality Analysis for The City of Akron's Water Treatment Plant and Distribution System

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Operational And Water Quality Analysis for The City of Akron's Water Treatment Plant and Distribution System

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Table of Contents

LIST OF TABLES AND FIGURES

SECTION 1: INTRODUCTION

Potable water is one of our most valuable resources. Producing it is costly and requires multiple unit operations in order to ensure a safe final product. Chlorination is one of the most common methods of treating pathogens and ensuring microbial water quality. As chlorinated water leaves the source and travels through the water distribution system, the chlorine reacts with both the organic compounds (dissolved organic carbon, DOC) in the source water and the corrosion or biofilm of the pipe walls. The chlorine concentration, or chlorine residuals, at any point in the water distribution system is a good measure of water quality. Often times, water distributors must drain millions of gallons of water through bleeders in order to maintain a suitable level of water quality. At the same time, chlorination produces disinfection byproducts as the chlorine also reacts with other naturally-occurring materials in the water. Some of these byproducts, including trihalomethanes (THM), pose health risks. It is therefore extremely important for water distributors to balance pathogen treatment with disinfection byproduct production in order to protect the health of their consumers.

1.1 Project Scope

This project is based on an updated and calibrated model of the water distribution system for the City of Akron, Ohio, see Figure 1. EPANET hydraulic modeling software integrated with Matlab computational software will be used to create a multi-species model of the water quality in the system. This model will be calibrated to data collected by the City of Akron for chlorine residual and THM formation at various test locations. Matlab will be used to analyze the effect of chlorine dose at the plant, water quality leaving the plant, and water age (sampling time) on chlorine residual and THM formation at test locations. This information will then be used to determine the most effective operational process for water quality management.

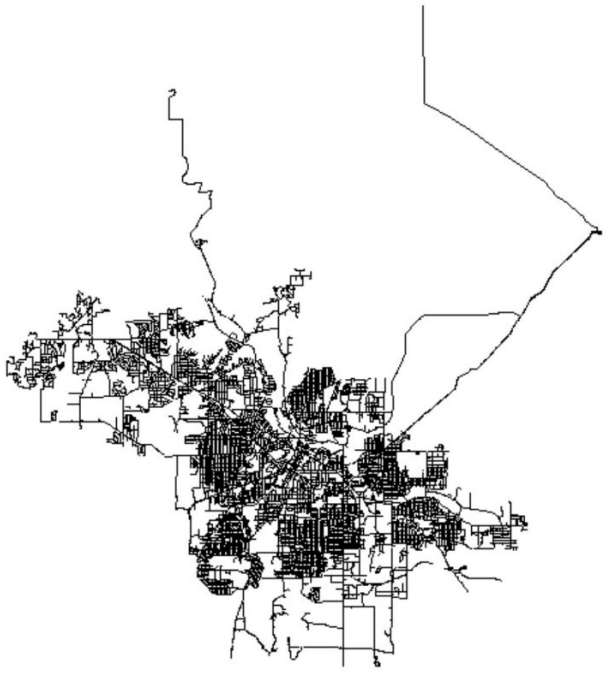

Figure 1 Schematic of the City of Akron's Drinking Water Distribution System EPANET model.

1.2 Objectives

- Integrate EPANET and Matlab software.
- Calibrate a mathematical water quality model to the City of Akron's Water Distribution System.
- Analyze operational management methods:
    - Analyze the effect of varying the chlorine dose at the water treatment plant on chlorine residual and THM formation.
    - Analyze the effect of water quality leaving the water treatment plant (DOC of source water) on chlorine residual and THM formation.
    - Analyze the relationship between water age (sampling time) on chlorine residual and THM formation.
- Determine what operational management method the water treatment plant should use to more efficiently control water quality in the system.

SECTION 2: BACKGROUND

2.1 The City of Akron

The City of Akron Water Plant Division treats approximately 35 million gallons a day (MGD) and serves multiple cities including Akron, Tallmadge, Stow, Fairlawn, Cuyahoga Falls, Twinsburg, Hudson, Mogadore and various townships. This large group of clients contribute to the water treatment plants nearly 300,000 service population[1]. Servicing such a large area requires an expansive and complex water distribution system.

In 2015, the City of Akron contracted ARCADIS, an engineering firm with a local presence and experience in water treatment and distribution, to develop a calibrated model of their water distribution system. With an accurate model of the system, the City of Akron can more efficiently evaluate hydraulic parameters of the system, analyze operational changes and future service areas, plan for future supply and demand growth, as well as, analyze water quality. The calibrated model developed by ARCADIS is used as the hydraulic model in this project.

2.2 EPANET Software

EPANET software[2] is commonly used to perform hydraulic analyses of water distribution networks. Networks consist of nodes (junctions), pipes (links), pumps and valves. Nodes can represent source points, consumption points, or storage facilities. Demand patterns are created to simulate usage for specific nodes, or regions of the system. Pump curves are included for each pump to simulate pump behavior and controls are created for tank operation.

The model developed by ARCADIS is used as the EPANET input. The City of Akron's distribution system is a complex system of over 32,400 nodes, 36,100 links, 10 tanks and one reservoir. For smaller systems, EPANET software is well suited for simple analyses, unfortunately, it is difficult, cumbersome, and lacks simple data extraction tools to analyze large systems such as the City of Akron's.

2.3 EPANET-Matlab Integration

Matlab is a desktop application that combines a computational interface with a programming language developed by MathWorks[3]. It is a highly versatile program that can easily manipulate large data sets. A dynamic link library (DLL) is available for EPANET (EPANET Toolkit) which allows complete control of an EPANET network through the Matlab interface. This capability is extremely powerful and is used in research across the country to analyze various aspects of water distribution systems. In this project, it is used to fill the voids in the data analyzation and water quality modelling pitfalls of EPANET alone.

A main component of this project was documenting how to integrate the two programs for use in future research at the University of Akron. The integration of the two programs is complicated by the varying architectures of the EPANET Toolkits, the configuration of the machine, and the different versions of Matlab. Various versions of the EPANET Toolkit are available for download for free from KIOS-Research[4].

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[1] http://www.akronohio.gov/cms/Water/
[2] The EPANet software download is available from the United States Environmental Agency at http://www.epa.gov/nrmrl/wswrd/dw/epanet.html.
[3] http://www.mathworks.com/?refresh=true
[4] https://github.com/KIOS-Research/EPANET-Matlab-Toolkit

The following is an overview of how to integrate Matlab and EPANET:

1. Download the entire EPANET-Matlab Toolkit from: https://github.com/KIOS-Research/EPANET-Matlab-Toolkit
2. Download and install any version of Matlab.
3. Install a compatible C compiler. Each version of Matlab has specific compatible compilers, the lists are located here: http://www.mathworks.com/support/compilers/R2016a/index.html
4. Copy the contents of the zip file to a new folder in Matlab.
5. In Matlab, set the new folder as the working directory.
6. From the 'libraries' folder, copy the compatible epanet2.dll and epanet2.h files. There are two library versions, 32-bit and 64-bit. The library version must match the Matlab version in order for the library to load and function properly in Matlab.
7. Use the 'RunTests' script included with the download to confirm that they are integrated successfully:
   - Confirm that the 'RunTests' script is located in the working directory.
   - Open the 'Networks' folder and copy 'Net2_Rossman.inp' into the working directory (the input for the 'RunTests' script).
   - Run the 'RunTests.m' file.

For specific details on the integration of EPANET and Matlab on Windows 7 and Windows 10 operating systems, see Appendix D.

SECTION 3: MODEL DEVELOPMENT

3.1 Governing Equations

Public water drinking systems must maintain a minimum level of chlorine residual in the system in order to ensure safe distribution. At the same time, they must minimize the harmful chemical species produced as a result of the disinfection process. One such species of concern are trihalomethanes (THM) which are produced as the chlorine reacts with the organic compounds (DOC) of the source water leaving the plant. Accurately quantifying chlorine consumption and THM formation are important to predicting chlorine residual and THM formation compliance.

Traditionally, chlorine decay models are primarily based on two components, wall demand and bulk water decay. The first-order kinetic model typically used to model chlorine decay in the bulk water phase is as follows[5]:

$$\frac{dc}{dt} = -kc \tag{1}$$

Where *c* is the initial chlorine concentration (mg/L), *k* is the first-order decay constant (min^{-1}), and *t* is the time or water age (min). Integrating equation (1) yields the following solution:

$$C(t) = C_o e^{-kt} \tag{2}$$

Where *C(t)* is the chlorine concentration (mg/L) at any reaction time *t*.

While many models use these kinetics, the study *Chlorine Demand and TTHM Formation Kinetics: A Second-Order Model* by Clark[5], demonstrated that a second order reaction kinetics model is just as accurate. This study developed the following equations for chlorine decay and THM formation:

$$Cl(t) = \frac{Cl_o(1-R)}{1-Re^{-ut}} \tag{3}$$

Where *Cl(t)* is the chlorine concentration in the system (mg/L) at any reaction time (water age) and Cl_o is the initial chlorine concentration or chlorine dose (mg/L). *R* (dimensionless) and *u* (hr^{-1}) are parameters specific to the chlorine decay kinetics of the distribution system. THM formation is then:

$$THM = T\left\{Cl_o - \left[\frac{Cl_o(1-R)}{1-Re^{-ut}}\right]\right\} \tag{4}$$

Where *T* is a characteristic of the quality of the source water, with units µg/L of THM formed per mg/L of chlorine consumed.

Equations (3) and (4) are used in the Matlab analysis of the City of Akron's distribution system to analyze the following:

- The effect of varying the chlorine dose (Cl_o) at the water treatment plant on chlorine residual (*Cl(t)*) and THM formation (*THM*).

[5] Clark, R. M. (1998). Chlorine Demand and TTHM Formation Kinetics: A Second-Order Model. *Journal of Environmental Engineering,* 16-24.

- The effect of water quality leaving the water treatment plant (*T*) on chlorine residual *(Cl(t))* and THM formation (*THM)*.

- The relationship between water age (*t*) on chlorine residual *(Cl(t))* and THM formation (*THM)*.

3.2 Model Calibration

In order to use the equations outlined in the precious section, the coefficients of *R* and *u*, as well as, the value of *T*, have to be calibrated to the water distribution system using field data. Residual chlorine readings are obtained weekly for test sites (nodes) across the distribution network and disinfection byproduct readings are obtained monthly. There are seven nodes with both residual chlorine and DBP data for the month of April 2014, see Table 1 for an overview of the data and Appendix B for field data. The chlorine residual value was averaged over the readings from the month of April 2014.

Table 1 Overview of data used in the calibration of chlorine kinetics parameters *R* and *u*, and water quality parameter *T*.

Node	From Model	From Field Data April 2014	
	Water Age (Time)	Cl (mg/L)	THM(μg/L)
J24814	104.1269	0.7075	35.1
J36278	129.7716	0.9133	37.1
J41572	376.7106	0.7125	35.8
J55958	124.2189	0.86	37.4
J56656	233.7578	0.7375	34.1
J73654	97.4265	0.8225	37.2
J86024	109.1758	0.984	35.9

The water age (variable *t*) is a measure of how long the water has been in the system by the time it reaches a node for use. This is highly variable across the system and depends on distance from the source, as well as, the demand in a given region, see Appendix A for an overview of the water age regions across the system. Water age also varies throughout the day. When there is higher demand (in the morning hours) the water age tends to be lower and conversely, higher during periods of low demand. Most field sampling occurs between the workday hours of 8:00am and 5:00pm and is often done in the morning when the water age is the lowest. The lower the water age, the less time it has been in the system, therefore the more chlorine residual and less THM present. The water age data for the nodes of interest was extracted from the EPANET model using Matlab, see Appendix C for code. It was extracted at 10:00am, the average sampling time, and is tabulated in Table 1.

The coefficients *R, u*, and the value of *T* were calibrated to the field data using excel solver. To do this, arbitrary values were chosen for the coefficients. The chlorine residual and THM formation were calculated using equations (3) and (4) assuming an initial chlorine dose of 3mg/L. The normalized sum square error (NSSE) was calculated for each node between the calculated value and the field data. The sum of the NSSE was optimized using excel solver. The constraints placed on the coefficients, the final NSSE and the calibrated coefficients are outlined in Table 2. The entire excel solver spreadsheet and additional information regarding the optimization can be found in Appendix C.

Table 2 Results and constraints used in the Excel Solver optimization of the normalized sum square error for the calibration of the EPANET-Matlab model to field data.

		Calibrated Result	
Variables	**Constraints**	**April 2014**	**April 2015**
Chlorine Dose	Constant	3.0	2.1
R	$0 \le R \le 1$	0.748669	0.748669
u	$0 \le u \le 1$	0.020450	0.020450
T	$0 \le T \le 100$	16.353782	14.25239
	Optimized NSSE	0.093865572	0.89241961

The optimization was then performed assuming the same chlorine kinetic coefficients of *R* and *u* and the chlorine dose from 2015. From the data in Table 2, the percent change in chlorine dose and *T* were calculated:

$$Cl\ Dose\ \%\ change = \frac{3.0-2.1}{3.0} x\ 100 = 30\% \quad (5)$$

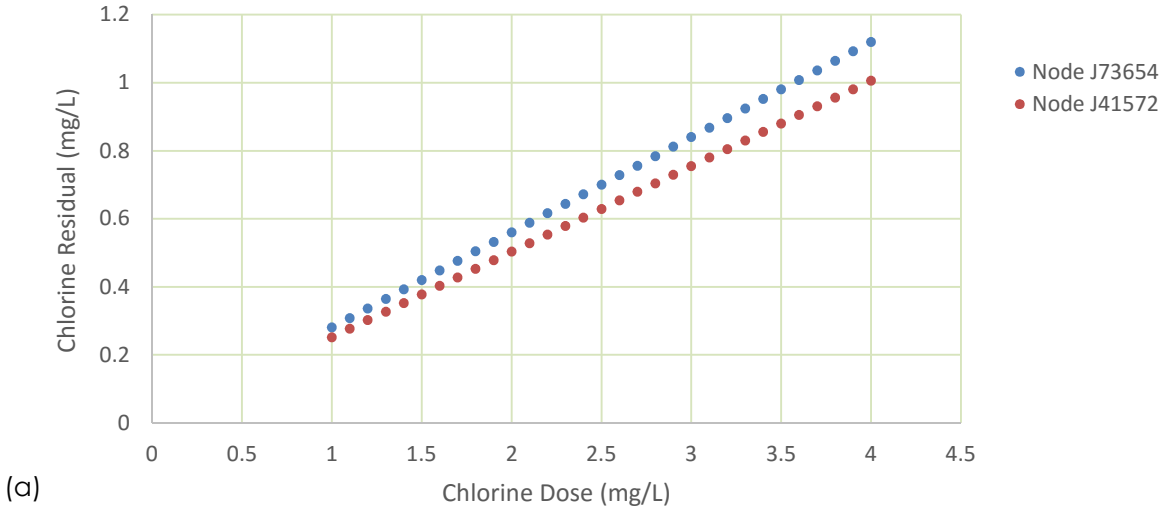
$$T\ \%\ change = \frac{16.4-14.2}{16.4} x\ 100 = 13\% \quad (6)$$

SECTION 4: RESULTS AND DISCUSSION

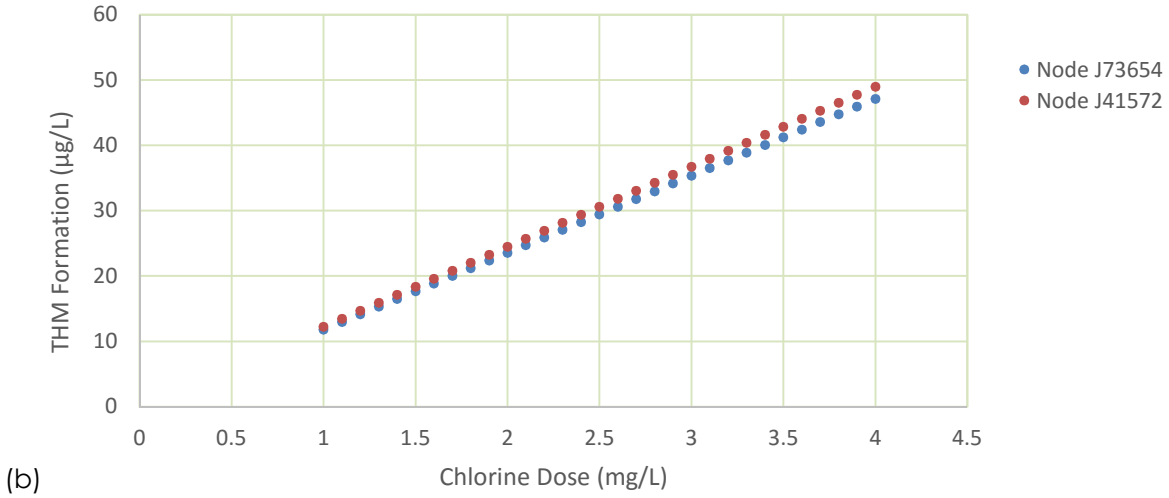
4.1 Simulations

Multiple simulations were performed on the EPANET model, using the calibrated equations for chlorine residual and THM formation. The Matlab code used to extract data from the EPANET model and perform the data analysis is located in Appendix C.

The aim of the first simulation was to analyze the effect of varying the chlorine dose at the water treatment plant on chlorine residual and THM formation. The coefficients of *R, u, and the value of* T were held constant from the calibration, see Table 2. The chlorine dose (Cl_o) was varied from 1mg/L to 4mg/L at an increment of 0.1mg/L. The results for the nodes with the best and worst water quality are shown in *Figure* 2.



(a)



(b)

Figure 2 (a) Chlorine Residual and (b) THM formation corresponding to incremental chlorine doses, 1 mg/L to 4 mg/L, from the Matlab analysis of the EPANET model. Coefficients R, u, and T used in the calculations are constants from the calibration of the mathematical equations to field data from April of 2014; their values are 0.748669 (dimensionless), 0.02045h^{-1}, and 16.35378 µg/L per mg/L of chlorine consumed, respectively. Results shown are for the test nodes of highest and lowest water quality.

The aim of the second simulation was to analyze the effect of water quality leaving the water treatment plant (DOC of source water) on chlorine residual and THM formation. The coefficients of *R* and *u* are as outlined in Table 2. The highest chlorine dose from the previous simulation, 4mg/L, was the Cl_o. The water quality leaving the plant, *T*, was varied from 4 to 32 µg/L per mg/L of chlorine consumed at an increment of 4 to 32 µg/L per mg/L of chlorine consumed. The results for the nodes with the best and worst water quality are shown in Figure 3.

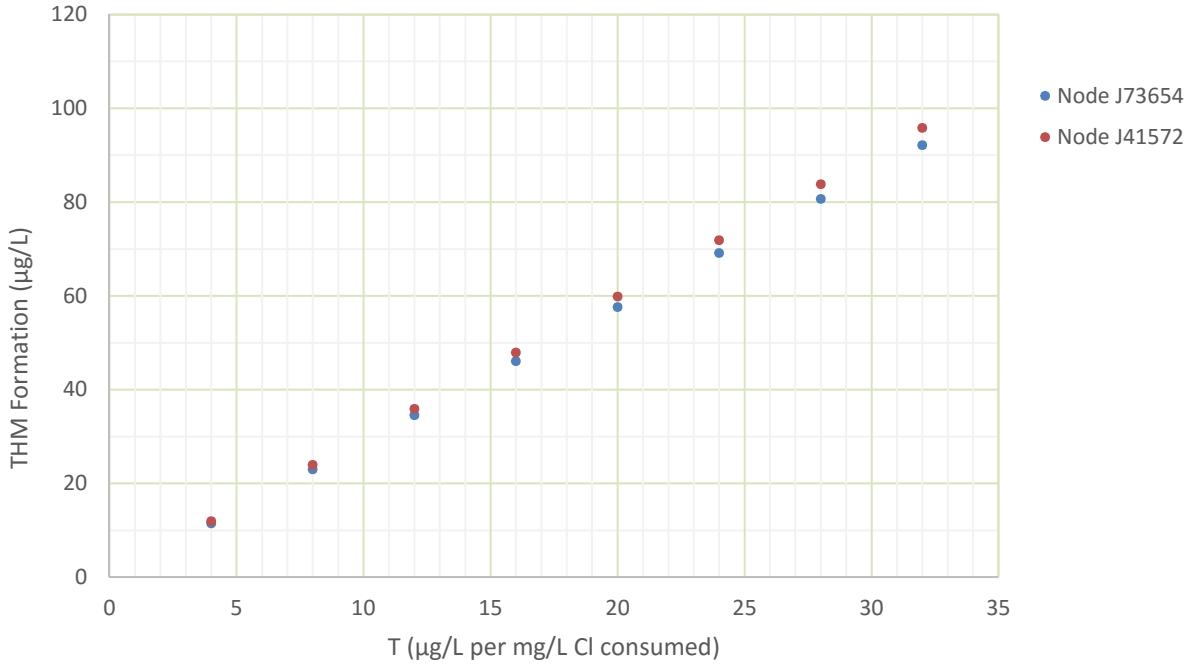


Figure 3 THM formation corresponding to incremental values of T, 4 to 32 µg/L per mg/L of chlorine consumed, and chlorine dose of 4 mg/L, from the Matlab analysis of the EPANET model. Coefficients R and u used in the calculations are constants from the calibration of the mathematical equations to *field data from April of 2014, their values are 0.748669 (dimensionless) and 0.02045h^{-1}, respectively*. Results shown are for the *test nodes of highest and lowest water quality*.

The aim of the third simulation was to analyze the relationship between water age (sampling time) on chlorine residual and THM formation. For this simulation, the coefficients of *R, u, and the value of* T were held constant from the calibration, see Table 2. The highest chlorine dose from the previous simulation, 4mg/L, was Cl_o. The water age data was extracted from EPANET using Matlab for sampling times between 8:00am and 5:00pm. Results for the node of lowest water quality are shown in Figure 4.

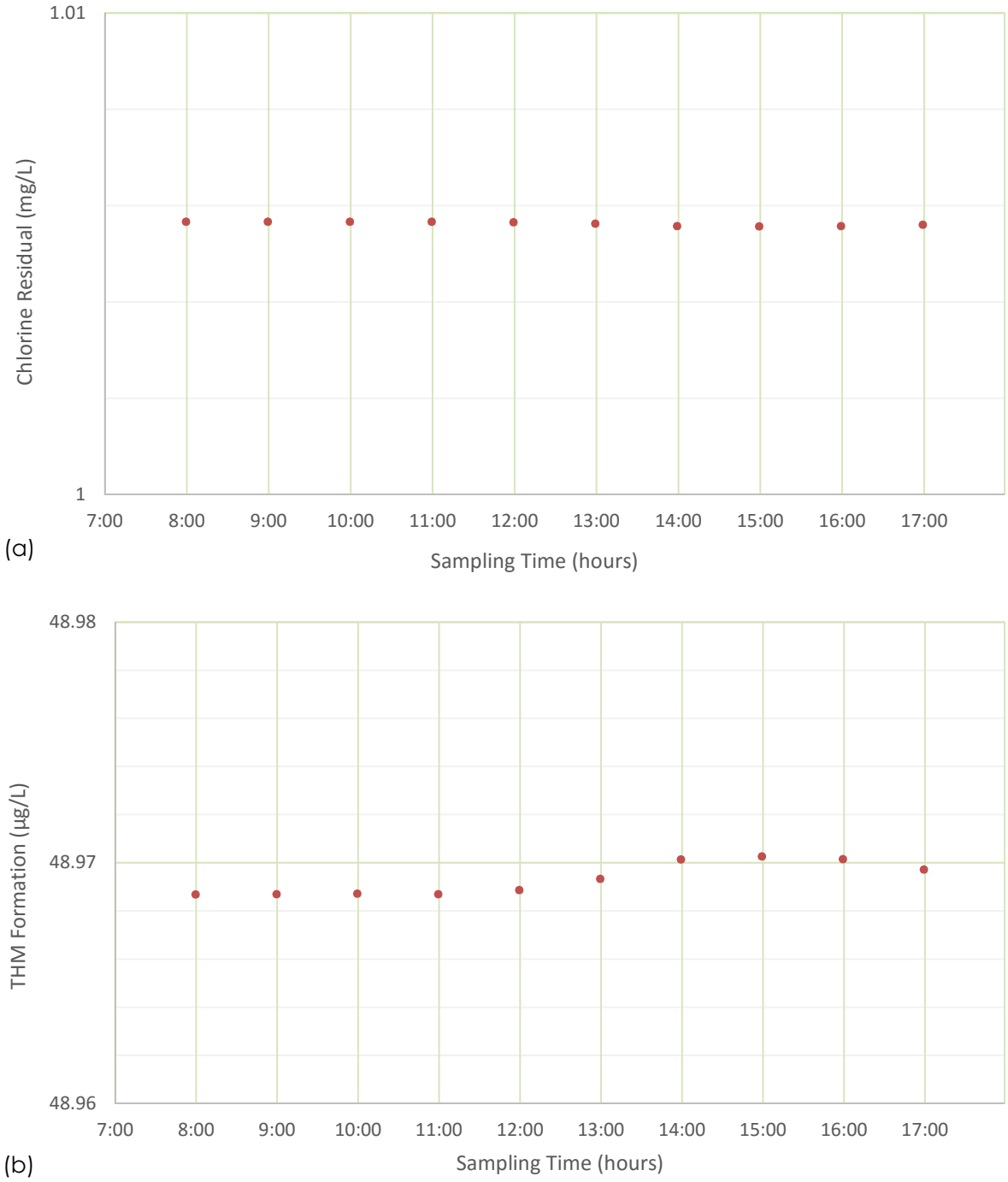


Figure 4 (a) Chlorine Residual and (b) THM formation for different sampling times during a standard work day (8:00am to 5:00pm), and chlorine dose of 4 mg/L, from the Matlab analysis of the EPANET model. Coefficients R, u, and T used in the calculations are constants from the calibration of the mathematical equations to field data from April of 2014; their values are 0.748669 (dimensionless), 0.02045h^{-1}, and 16.35378 µg/L per mg/L of chlorine consumed, respectively. Results shown are for the test node of lowest water quality, Node 41572.

The final simulation was performed on the node of the lowest water quality, Node 41572. The aim of the simulation was to quantify the relationship between chlorine dose and *T* value to

determine whether it is more efficient to treat THM formation by changing the chlorine dose or *T* value (water quality leaving the plant).

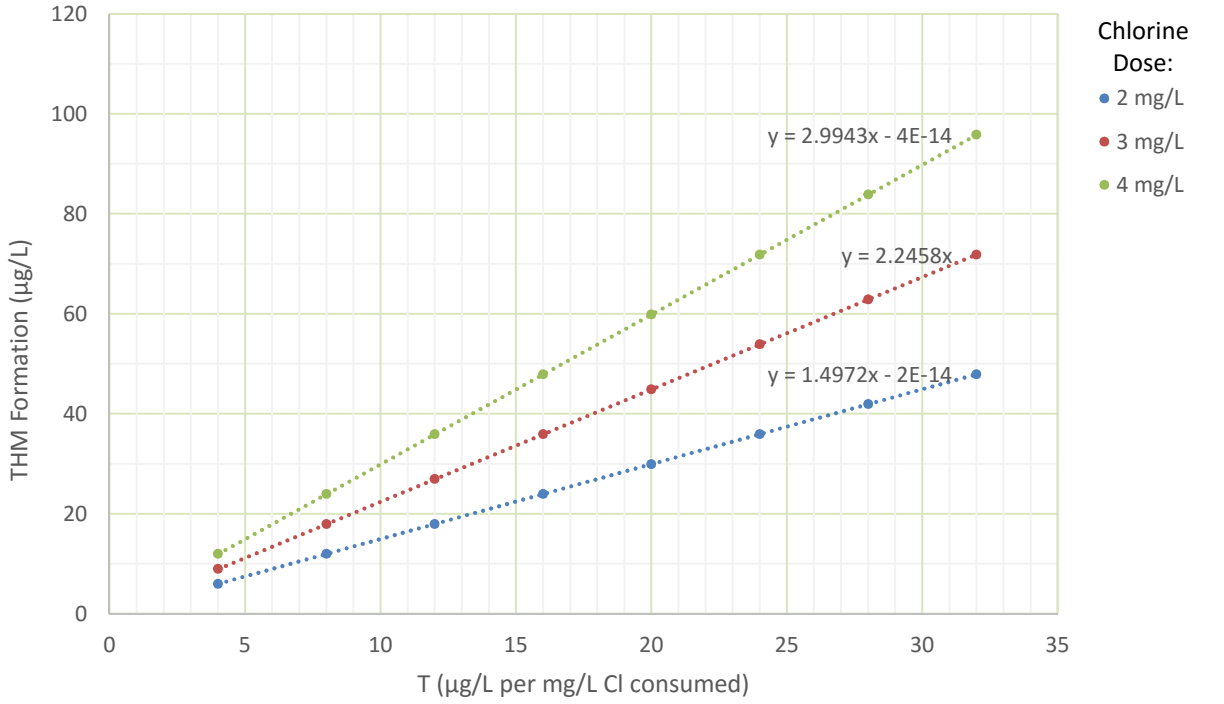


Figure 5 THM formation corresponding to incremental values of T, 4 to 32 µg/L per mg/L of chlorine consumed, and chlorine doses of 2 mg/L to 4mg/L, from the Matlab analysis of the EPANET model. Coefficients R and u used in the calculations are constants from the calibration of the mathematical equations to *field data from April of 2014, their values are 0.748669 (dimensionless) and 0.02045h^{-1}, respectively*. A linear trend line was fitted to each of the results for analysis. Results shown are for the test node of lowest water quality, Node 41572.

In order to quantitatively compare the results, the data in Table 3 was extracted from Figure 5. The data from Figure 5 was used to determine the change in *T* required to decrease the THM formation from 80 to 60 µg/L. A linear interpolation was performed on the data from Table 3 to determine the chlorine dose required to decrease the THM formation from 80 to 60 µg/L at a constant *T* value of 30 µg/L per mg/L Cl consumed, see Table 4.

Table 3 THM formation (µg/L) extracted from Figure 5 for a constant T value of 30 µg/L per mg/L Cl consumed at the chlorine doses of 4, 3, and 2mg/L.

T = 30 µg/L per mg/L Cl consumed	
Chlorine Dose (mg/L)	THM Formation (µg/L)
4	89.829
3	67.374
2	44.916

Table 4 The change in *T* value and Chlorine dose required to decrease the THM formation from 80 to 60 µg/L at a constant chlorine dose of 4mg/L and constant *T* value of 30 µg/L per mg/L Cl consumed, respectively.

	Constant Chlorine Dose	Constant T
THM (µg/L)	T (µg/L per mg/L Cl consumed)	Chlorine Dose (mg/L)
80	26.72	3.56
60	20.04	2.67
Change in Parameter	**6.68**	**0.89**

4.2 Results and Conclusions

The graphs of *Figure 2* demonstrate the general linear trend between chlorine dose and its effect on chlorine residual and THM formation. The higher the dose, the greater amount of chlorine residual in the system, as well as, greater THM formation. They also show that the difference between the nodes of highest and lowest quality is minimal.

Figure 3 demonstrates that the general trend between the *T* value and THM formation is also linear. It also demonstrates that the higher the *T* value (the lower the quality of the water leaving the plant) the higher the THM formation.

The graphs of Figure 4 demonstrate that the water sampling time, or water age, has very little effect on both chlorine residual and THM formation. Chlorine residual and THM formation were plotted over an entire work day of sampling times and there is very little change. Water sampling time is therefore not an effective way of ensuring compliance with regards to chlorine residual and THM formation.

The accuracy of the excel solver calibration outlined in Section 3.2 was verified by additional calculations completed by Dr. Miller. Analyzing data from recent years, he calculated the average *T* value to be 16 with a minimum of 6 and maximum of 40, in units of µg/L of THM produced per mg/L of chlorine consumed. This confirms the accuracy of the calibration, not only with respect to *T*, but the chlorine kinetic coefficients of *R* and *u*. With the accuracy of the chlorine kinetic coefficients confirmed, the calibration was performed again to reflect the chlorine dose from April of 2015, as outlined in Table 2. The chlorine dose in 2015 was 0.9 mg/L lower than April 2014 and the *T* value calculated was 14.2 µg/L of THM produced per mg/L of chlorine consumed. Equations 5 and 6 calculated the percent change of chlorine dose as 30% and the percent change of *T* as 13%. This alludes to the idea that chlorine dose is more of a driver of THM formation than the *T* value associated with the water quality leaving the plant.

This hypothesis is further supported by the data from Figure 5 and Tables 3 to 4. Table 4 shows that in order to decrease the THM formation from 80 to 60 µg/L, the water treatment plant would need to decrease the *T* value by 6.68 µg/L per mg/L of chlorine consumed. This is an expensive process that requires a significant increase in additional chemicals. The table also shows that for the same THM decrease, the chlorine dose would only need to decrease by 0.89 mg/L. Operationally, this is a cheap and easy correction. This shows that operationally, the most effective method of controlling THM formation and chlorine residual in the water distribution system is to focus on changing the chlorine dose for different distribution system conditions.

APPENDICES

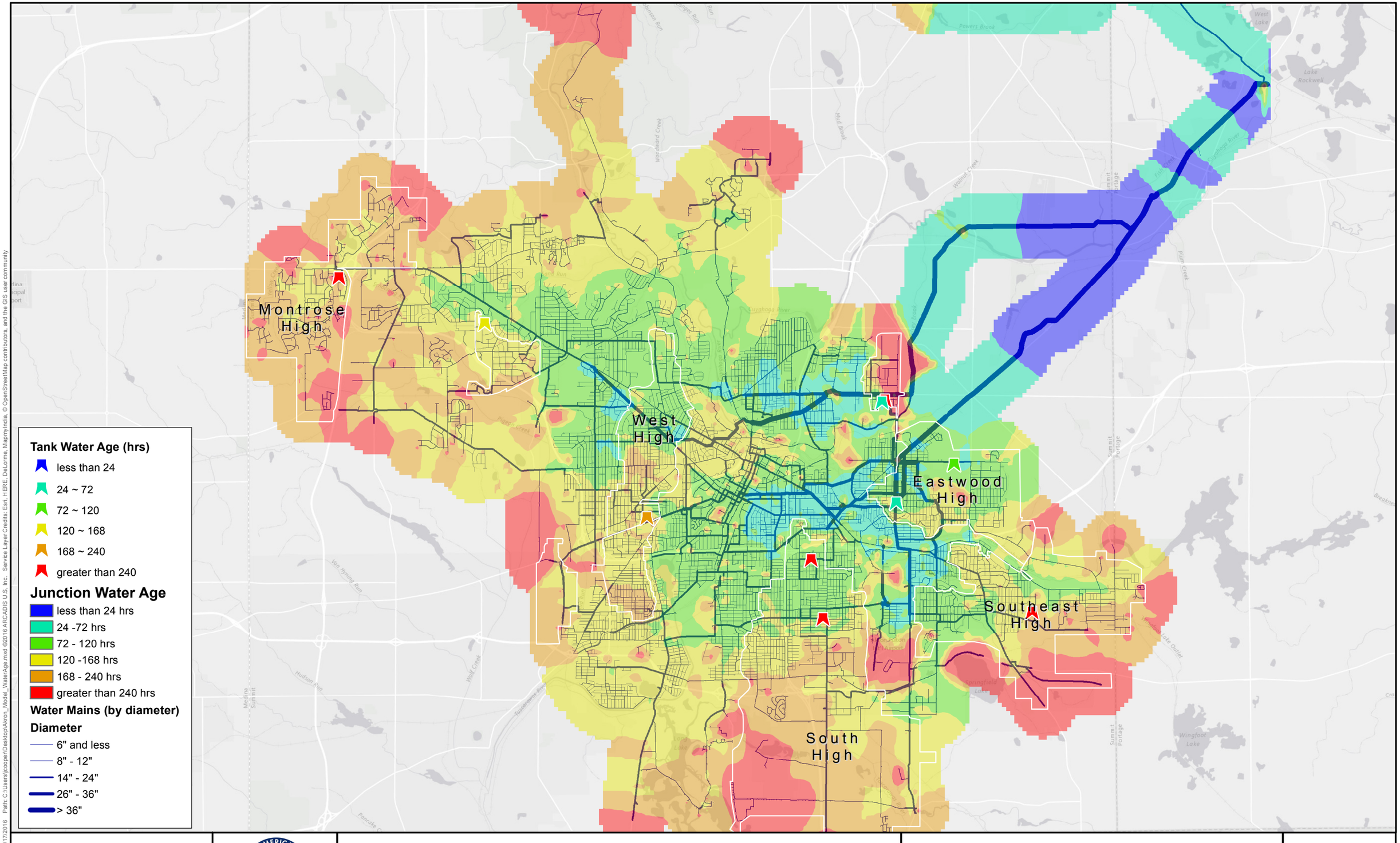
Appendix A – Water Age Map from ARCADIS

Appendix B – Field Test Data

Appendix C – Excel Solver and Matlab Code

Appendix D – Matlab/Epanet Integration Manual for Windows 7 and Windows 10 Operating Systems

Appendix A – *Water Age Map from ARCADIS*



ARCADIS

City of Akron, Ohio

Water Distribution System Hydraulic and Water Quality Model

Project No.: AK000332.R001

Water Distribution System
300 Hour Water Age Simulation Results

FIGURE

Appendix B – *Field Test Data*

Chlorine Readings Node J56656

4514 Swan Lake, sample station	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/03/14	0.67	0.20	0.87	0.89	1.58	31.19
01/10/14	0.81	0.21	1.02	0.86	1.71	35.25
01/24/14	0.90	0.15	1.05	0.80	1.78	40.72
02/07/14	1.02	0.19	1.21	0.88	1.85	34.63
03/21/14	0.83	0.14	0.97	0.91	1.73	31.39
03/28/14	0.86	0.15	1.01	0.89	1.75	39.74
04/04/14	0.83	0.17	1.00	0.85	1.81	31.76
04/11/14	0.52	0.18	0.70	0.67	1.62	35.40
04/18/14	0.41	0.20	0.61	0.50	1.98	33.17
04/25/14	0.42	0.22	0.64	0.46	2.23	25.18
05/02/14	0.57	0.31	0.88	0.55	2.17	37.01

	April Average	0.7375

Chlorine Readings Node J73654

Blair House Apartments, main floor	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/08/14	1.30	0.19	1.49	0.89	1.91	35.68
01/22/14	1.01	0.17	1.18	0.86	1.69	32.34
02/05/14	1.00	0.12	1.12	0.95	1.65	40.12
02/12/14	1.05	0.22	1.27	0.91	1.78	34.98
02/19/14	1.15	0.19	1.34	1.03	1.72	40.37
02/26/14	1.37	0.21	1.58	0.89	1.99	40.37
03/05/14	1.25	0.22	1.47	1.01	1.55	36.91
03/12/14	1.11	0.14	1.25	1.04	1.82	30.99
03/19/14	1.15	0.06	1.21	0.91	1.75	36.20
03/26/14	0.92	0.15	1.07	0.92	1.89	31.54
04/09/14	0.54	0.19	0.73	0.78	1.76	31.65
04/16/14	0.62	0.17	0.79	0.55	2.01	31.69
04/23/14	0.72	0.17	0.89	0.48	1.93	25.13
04/30/14	0.63	0.25	0.88	0.51	2.32	39.52

	April Average	0.8225

Chlorine Readings Node J55958

Fire Station # 5, coat room utility sink	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/14/14	0.84	0.26	1.10	0.88	1.77	32.17
01/21/14	0.90	0.14	1.04	0.83	1.88	40.42
01/28/14	1.02	0.18	1.20	0.82	1.74	40.04
02/04/14	0.96	0.21	1.17	0.92	1.85	33.11
02/11/14	1.12	0.19	1.31	0.89	1.81	40.47
02/18/14	1.17	0.12	1.29	0.98	1.80	39.63
02/25/14	1.01	0.19	1.20	0.98	1.91	36.82
03/11/14	0.82	0.23	1.05	1.06	1.81	39.91
03/18/14	0.76	0.15	0.91	0.97	1.81	34.19
03/25/14	0.99	0.13	1.12	0.90	1.92	31.35
04/01/14	0.98	0.19	1.17	0.83	1.65	40.77
04/08/14	0.57	0.20	0.77	0.81	1.76	31.47
04/22/14	0.47	0.18	0.65	0.48	2.03	38.33
04/29/14	0.64	0.21	0.85	0.49	2.21	28.54
05/06/14	0.41	0.23	0.64	0.62	2.07	37.11

	April Average	0.86

Chlorine Readings Node J86024

Firestation # 13, utility sink	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/14/14	1.15	0.04	1.19	0.88	1.77	32.17
01/21/14	1.15	0.16	1.31	0.83	1.88	40.42
01/28/14	1.12	0.19	1.31	0.82	1.74	40.04
02/04/14	1.06	0.17	1.23	0.91	1.85	33.11
02/11/14	1.23	0.14	1.37	0.89	1.81	40.47
02/18/14	1.26	0.18	1.44	0.98	1.80	39.63
02/25/14	1.37	0.03	1.40	0.98	1.91	36.82
03/11/14	1.10	0.22	1.32	1.06	1.81	39.91
03/18/14	1.07	0.20	1.27	0.97	1.81	34.19
03/25/14	1.09	0.14	1.23	0.91	1.92	31.35
04/01/14	0.99	0.16	1.15	0.86	1.65	40.77
04/08/14	0.79	0.19	0.98	0.81	1.76	31.47
04/15/14	0.77	0.13	0.90	0.59	1.85	31.59
04/22/14	0.65	0.19	0.84	0.48	2.03	38.33
04/29/14	0.86	0.19	1.05	0.49	2.21	28.54
05/06/14	0.69	0.18	0.87	0.62	2.07	37.11

	April Average	0.984

Chlorine Readings Node J41572

Main Street Muffins, utility sink	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/02/14	0.75	0.26	1.01	0.91	1.75	31.16
02/06/14	0.76	0.17	0.93	0.93	1.51	33.01
02/13/14	0.79	0.21	1.00	0.90	1.86	40.52
02/20/14	0.82	0.19	1.01	1.00	1.64	33.41
02/25/14	0.72	0.29	1.01	0.98	1.91	36.82
02/27/14	0.99	0.20	1.19	0.91	2.05	35.05
03/06/14	0.83	0.16	0.99	1.00	1.68	33.38
03/13/14	0.72	0.17	0.89	0.98	1.80	35.54
03/20/14	0.75	0.17	0.92	0.88	1.69	35.50
03/27/14	0.65	0.18	0.83	0.88	1.76	37.12
04/03/14	0.95	0.17	1.12	0.86	1.80	31.62
04/10/14	0.61	0.17	0.78	0.73	1.73	31.81
04/17/14	0.25	0.20	0.45	0.49	2.04	31.78
04/24/14	0.32	0.18	0.50	0.45	2.25	40.14
05/01/14	0.37	0.09	0.46	0.50	2.03	26.19

	April Average	0.7125

Chlorine Readings Node J36278

Sheetz Gas, restroom sink	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/06/14	0.80	0.24	1.04	0.88	1.89	33.70
01/13/14	0.90	0.18	1.08	0.88	1.91	40.51
01/27/14	0.95	0.17	1.12	0.81	1.92	40.79
02/10/14	1.11	0.05	1.16	0.89	2.18	34.67
02/24/14	1.05	0.22	1.27	0.97	1.96	40.33
03/03/14	1.08	0.16	1.24	1.00	1.75	40.70
03/10/14	1.08	0.18	1.26	1.07	1.85	40.67
03/24/14	1.05	0.15	1.20	0.89	1.82	31.36
03/31/14	0.88	0.14	1.02	0.86	1.83	34.69
04/07/14	0.77	0.18	0.95	0.84	1.98	32.29
04/15/14	0.70	0.19	0.89	0.60	1.85	31.59
04/28/14	0.69	0.21	0.90	0.49	2.26	35.13

April Average 0.913333333

Chlorine Readings Node J24814

Speedy Muffler King, restroom sink	Free Chlorine (mg/L)	Combined Chlorine (mg/L)	Free + Combined Chlorine (mg/L)	Average of last approx. 7 days free chlorine (mg/l)	Tap Free Chlorine for the Sample Day (mg/L)	Average Daily Flow from AWS Daily Pumpage
01/08/14	1.23	0.23	1.46	0.89	1.91	35.68
01/22/14	0.78	0.16	0.94	0.86	1.69	32.34
01/29/14	1.17	0.09	1.26	0.86	1.75	34.97
02/05/14	0.99	0.18	1.17	0.95	1.65	40.12
02/12/14	1.22	0.09	1.31	0.91	1.78	34.98
02/19/14	1.10	0.11	1.21	1.03	1.72	40.37
02/26/14	1.41	0.19	1.60	0.89	1.99	40.37
03/05/14	1.23	0.22	1.45	1.01	1.55	36.91
03/12/14	1.00	0.19	1.19	1.04	1.82	30.99
03/19/14	0.89	0.18	1.07	0.91	1.75	36.20
03/26/14	0.90	0.13	1.03	0.92	1.89	31.54
04/09/14	0.49	0.22	0.71	0.78	1.76	31.65
04/16/14	0.53	0.19	0.72	0.55	2.01	31.69
04/23/14	0.49	0.20	0.69	0.48	1.93	25.13
04/30/14	0.60	0.11	0.71	0.51	2.32	39.52

	April Average	0.7075

Akron, OH Stage 2 - Historical DBP Results

1. Yellow shaded areas generally require data input.
2. Please enter site results-enter zero if not detected.

2012-2015

THM LOS = 64

DS202 - 2456 E. Market Street

Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	22.0	6.4	0.0	13.8	1.8	XX	XX	21.2	0.0	0.0	0.0	12.5	8.7
4/10/12		XX	XX	51.1	12.6	0.0	35.7	2.8	XX	XX	34.4	0.0	0.0	0.0	18.9	15.5
7/10/12		XX	XX	65.6	17.5	0.0	42.9	5.2	XX	XX	40.5	7.0	1.5	0.0	17.0	15.0
10/9/12		181	43	33.2	9.3	0.0	21.5	2.4	144	30	22.6	0.0	0.0	0.0	12.7	9.9
1/8/13		170	45	30.6	6.2	0.0	23.1	1.3	143	33	35.1	0.0	0.0	0.0	21.8	13.3
4/9/13		191	39	27.8	8	0.0	16.9	2.9	142	28	15.5	0.0	0.0	0.0	10.7	4.8
7/9/13		228	45	88.4	17.1	0.0	67.7	3.6	167	28	37.1	0.0	4.3	0.0	10.9	21.9
10/8/13		173	54	70.2	13.3	0.0	53.6	3.3	152	30	32.3	0.0	0.0	0.0	17.0	15.3
1/14/14		134	52	20.2	5.5	0.0	12.4	2.3	155	26	18.8	0.0	0.0	1.0	11.2	6.6
4/8/14		141	54	37.4	7.6	0.0	28	1.8	152	28	25.4	0.0	0.0	0.0	15.7	9.7
7/8/14		192	64	126.4	17.6	0.0	107	1.8	164	33	55.8	0.0	0.0	0.0	11.5	44.3
10/14/14		136	66	79.4	14.5	0.0	62.4	2.5	140	37	47.8	0.0	0.0	0.0	17.3	30.5
1/13/15		77	64	12.9	3.8	0.0	8.1	1	111	41	36.0	0.0	0.0	0.0	24.0	12.0
4/13/15		101	60	22.7	6.1	0.0	15.2	1.4	100	48	51.9	0.0	5.1	0	31.6	15.2
7/8/15		205	41	50.1	8.6	0.0	40.2	1.3	104	43	34.4	0.0	0.0	0.0	12.7	21.7
#REF!		234	35	52.4	13.5	0.0	35.4	3.5	118	36	21.1	0.0	0.0	0.0	8.8	12.3
#REF!		195		0.0					133		0.0					

DS203 - 1544 Brown Street

Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	21.8	6.7	0.0	13.2	1.9	XX	XX	19.3	0.0	0.0	0.0	11.5	7.8
4/10/12		XX	XX	50.1	11.9	0.0	35.4	2.8	XX	XX	32.8	0.0	0.0	0.0	18.6	14.2
7/10/12		XX	XX	73.1	18.3	0.0	49.6	5.2	XX	XX	39.6	4.4	1.4	0.0	19.1	14.7
10/9/12		175	48	45.0	11.7	0.0	30.4	2.9	148	30	28.9	0.0	0.0	0.0	16.0	12.9
1/8/13		152	50	30.2	6.2	0	22.6	1.4	139	35	38.0	0.0	0.0	0.0	22.5	15.5
4/9/13		172	44	26.5	7.8	0	15.9	2.8	134	33	24.3	0.0	2.2	1.0	13.0	8.1
7/9/13		218	45	79.1	15.7	0	60.3	3.1	149	35	47.8	0.0	2.1	0.0	24.0	21.7
10/8/13		184	48	56.6	11.5	0	42.2	2.9	130	36	35.6	0.0	0.0	0.0	20.2	15.4
1/14/14		158	45	19.6	5.2	0	12.2	2.2	132	32	19.6	0.0	0.0	1.1	11.6	6.9
4/8/14		165	48	35.9	6.4	0	28	1.5	137	33	27.5	0.0	0.0	0.0	17.5	10.0
7/8/14		208	51	91.0	15.4	0	73.8	1.8	157	41	81.3	0.0	0.0	0.0	36.7	44.6
10/14/14		174	53	65.8	12.4	0	50.9	2.5	112	45	52.4	0.0	3.8	0.0	20.5	28.1
1/13/15		127	52	13.4	4.0	0.0	8.3	1.1	79	51	41.8	0.0	3.8	0.0	27.0	11.0
4/13/15		150	48	22.9	6.4	0.0	14.9	1.6	65	56	49.6	0.0	4.7	0	31.2	13.7
7/8/15		218	37	45.9	8.2	0.0	36.5	1.2	96	46	39.7	0.0	0.0	0.0	16.6	23.1
#REF!		238	34	51.9	13.0	0.0	35.7	3.2	109	37	17.5	0.0	0.0	0.0	7.7	9.8
#REF!		199		0.0					133		0.0					

DS205 4514 Swan Lake

Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	26.0	7.4	0.0	16.7	1.9	XX	XX	26.7	3.0	0.0	0.0	13.8	9.9
4/10/12		XX	XX	59.7	13.1	0.0	43.9	2.7	XX	XX	39.0	0.0	0.0	0.0	22.2	16.8
7/10/12		XX	XX	87.1	19.3	0.0	62	5.8	XX	XX	48.1	5.3	1.7	0.0	25.1	16.0
10/9/12		147	57	54.8	12.8	0.0	39	3	126	37	32.5	0.0	0.0	0.0	17.1	15.4
1/8/13		118	59	33.2	7	0	24.8	1.4	120	37	29.1	0.0	0.0	0.0	16.4	12.7
4/9/13		145	51	27.8	8	0	16.9	2.9	130	33	20.8	0.0	0.0	1.0	12.1	7.7
7/9/13		204	64	138.6	21.3	0	114	3.3	158	34	52.1	0.0	0.0	0.0	25.9	26.2
10/8/13		120	70	80.1	13.3	0	63.6	3.2	138	35	39.2	0.0	0.0	0.0	19.6	19.6
1/14/14		73	68	23.6	6.2	0	15.1	2.3	128	34	23.7	0.0	0.0	1.2	13.6	8.9
4/8/14		78	69	34.1	7.4	0	24.5	2.2	125	35	25.2	0.0	0.0	0.0	15.4	9.8
7/8/14		182	68	133.6	16.8	0	115	1.8	152	42	81.5	0.0	0.0	0.0	35.1	46.4
10/14/14		129	71	90.8	15.5	0	72.7	2.6	110	48	59.8	0.0	0.0	0.0	26.7	33.1
1/13/15		62	68	15.0	4.4	0.0	9.2	1.4	74	53	47.0	0.0	0.0	0.0	32.0	15.0
4/13/15		81	67	27.2	7.1	0.0	18.3	1.8	52	62	59.9	0.0	4.2	0.0	37.3	18.4
#REF!		187	48	59.5	9.1	0.0	49.0	1.4	73	50	33.4	0.0	0.0	0.0	4.1	29.3
#REF!		218	41	63.4	14.4	0.0	45.4	3.6	100	40	21.0	0.0	0.0	0.0	8.8	12.2
#REF!		170		0.0					126		0.0					

DS206 - 1680 W. Market Street

Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	19.1	5.4	0.0	12.0	1.7	XX	XX	13.5	0.0	0.0	0.0	8.3	5.2
4/10/12		XX	XX	37.2	10.0	0.0	24.5	2.7	XX	XX	21.0	0.0	0.0	0.0	12.2	8.8
7/10/12		XX	XX	129.5	20.9	0.0	105.0	3.6	XX	XX	83.5	0.0	0.0	0.0	43.9	39.6
10/9/12		134	54	29.4	8.8	0.0	18.0	2.6	122	35	20.6	0.0	0.0	0.0	11.7	8.9
1/8/13		124	55	25.1	5.7	0.0	18.1	1.3	115	35	16.2	0.0	0.0	0.0	10.6	5.6
4/9/13		136	52	23.9	7.2	0.0	14.1	2.6	120	36	22.4	0.0	0.0	1.1	14.4	6.9
7/9/13		242	43	92.7	17.9	0.0	71.4	3.4	181	26	45.3	0.0	0.0	0.0	25.5	19.8
10/8/13		178	49	54.9	10.6	0.0	41.4	2.9	156	30	35.8	0.0	0.0	0.0	20.0	15.8
1/14/14		149	48	19.4	5.4	0.0	11.9	2.1	137	30	18.3	0.0	0.0	1.1	10.9	6.3
4/8/14		153	51	35.1	6.8	0.0	26.7	1.6	141	32	29.8	0.0	0.0	0.0	19.8	10.0
7/8/14		211	56	113.2	15.3	0.0	96.2	1.7	156	40	76.4	0.0	0.0	0.0	32.6	43.8
10/14/14		152	64	88.3	15.5	0.0	70.6	2.2	116	46	58.0	0.0	3.8	0.0	27.4	26.8
1/13/15		83	61	8.3	2.6	0.0	5.2	0.5	76	47	24.5	0.0	0.0	0.0	18.0	6.5
4/13/15		110	57	16.4	4.8	0.0	10.4	1.2	81	49	38.8	0.0	0.0	0.0	27.6	11.2
#REF!		207	39	42.5	7.7	0.0	33.6	1.2	119	40	38.7	0.0	0.0	0.0	15.3	23.4
#REF!		253	29	47.1	12.3	0.0	31.7	3.1	138	31	21.1	0.0	0.0	0.0	11.6	9.5
#REF!		214		0.0					141		0.0					

DS207 - 20 W. Waterloo Road

Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	20.3	6.4	0.0	12.0	1.9	XX	XX	21.4	0.0	0.0	0.0	12.8	8.6
4/10/12		XX	XX	53.4	12.9	0.0	37.8	2.7	XX	XX	37.4	0.0	0.0	0.0	20.5	16.9
7/10/12		XX	XX	78.7	18.8	0.0	54.4	5.5	XX	XX	44.7	7.1	1.5	0.0	19.4	16.7
10/9/12		168	51	51.2	13.1	0.0	34.9	3.2	137	34	31.8	0.0	0.0	0.0	17.7	14.1
1/8/13		137	54	31.1	6.6	0.0	23.1	1.4	126	34	23.5	0.0	0.0	0.0	14.1	9.4
4/9/13		159	47	26.8	7.6	0.0	16.4	2.8	140	30	21.0	0.0	2.8	0.0	11.1	7.1
7/9/13		211	54	108.0	18.9	0.0	85.7	3.4	164	31	48.5	0.0	0.0	0.0	26.0	22.5
10/8/13		154	57	60.3	12.1	0.0	45.3	2.9	147	33	39.5	0.0	0.0	0.0	22.7	16.8
1/14/14		125	54	21.4	5.7	0.0	13.4	2.3	131	32	20.7	0.0	0.0	1.3	12.1	7.3
4/8/14		130	57	37.1	7.0	0.0	28.4	1.7	131	34	29.0	0.0	0.0	0.0	19.6	9.4
7/8/14		201	62	129.4	15.7	0.0	112.0	1.7	151	43	84.2	0.0	0.0	0.0	38.0	46.2
10/14/14		132	69	89.8	16.6	0.0	70.8	2.4	106	47	52.8	0.0	0.0	0.0	21.9	30.9
1/13/15		64	67	10.1	3.3	0.0	5.8	1.0	74	49	29.3	0.0	0.0	0.0	21.0	8.3
4/13/15		91	64	24.7	6.3	0.0	17.0	1.4	74	56	58.7	0.0	5.1	0.0	35.7	17.9
#REF!		195	45	56.8	9.3	0.0	46.1	1.4	99	47	47.1	0.0	0.0	0.0	17.5	29.6
#REF!		228	37	58.3	14.1	0.0	40.6	3.6	105	39	21.6	0.0	0.0	0.0	9.8	11.8
#REF!		180		0.0					113		0.0					

DS209 - 255 N. Portage Path

Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	14.8	5.2	0.0	7.8	1.8	XX	XX	15.4	0.0	0.0	0.0	9.5	5.9
4/10/12		XX	XX	43.8	11.6	0.0	29.5	2.7	XX	XX	23.9	0.0	0.0	0.0	14.1	9.8
7/10/12		XX	XX	62.8	16.7	0.0	41.2	4.9	XX	XX	41.3	0.0	0.0	0.0	24.3	17.0
10/9/12		199	39	34.0	9.6	0.0	21.9	2.5	159	26	22.0	0.0	0.0	0.0	12.4	9.6
1/8/13		179	42	26.7	5.5	0.0	20.0	1.2	153	31	37.3	0.0	0.0	0.0	21.1	16.2
4/9/13		197	37	25.5	7.3	0.0	15.3	2.9	139	30	19.4	0.0	0.0	1.0	11.3	7.1
7/9/13		234	50	113.1	19.0	0.0	90.7	3.4	161	29	38.6	0.0	0.0	0.0	15.7	22.9
10/8/13		155	57	64.0	12.7	0.0	48.2	3.1	145	33	38.4	0.0	0.0	0.0	21.4	17.0
1/14/14		117	56	20.3	5.3	0.0	12.8	2.2	144	29	20.0	0.0	0.0	1.2	11.8	7.0
4/8/14		123	59	37.2	7.0	0.0	28.4	1.8	143	31	28.4	0.0	0.0	0.0	18.6	9.8
7/8/14		199	60	119.9	16.1	0.0	102.0	1.8	153	41	76.0	0.0	0.0	0.0	31.3	44.7
10/14/14		143	69	97.9	16.2	0.0	79.1	2.6	116	40	36.7	0.0	0.0	0.0	8.2	28.5
1/13/15		65	66	8.6	2.7	0.0	5.2	0.7	99	42	26.3	0.0	0.0	0.0	19.0	7.3
4/13/15		94	62	20.6	6.3	0.0	12.5	1.8	101	45	39.4	0.0	0.0	0.0	27.7	11.7
#REF!		193	45	51.0	8.5	0.0	41.2	1.3	138	38	50.7	0.0	0.0	0.0	23.9	26.8
#REF!		240	32	46.9	12.0	0.0	31.6	3.3	124	34	20.9	0.0	0.0	0.0	11.1	9.8
#REF!		202		0.0					129		0.0					

				DS212 - 170 Muffin Lane												
Sample Date	THM LOS	Exceed #	THM LRAA	THM4 ug/L	Bromodichloromethane ug/L	Bromoform ug/L	Chloroform ug/L	Dibromochloromethane ug/L	Exceed #	HAA5 LRAA	HAA5 ug/L	Monobromoacetic Acid ug/L	Monochloroacetic Acid ug/L	Dibromoacetic Acid ug/L	Dichloroacetic Acid ug/L	Trichloroacetic Acid ug/L
1/10/12		XX	XX	38.2	9.4	0.0	26.4	2.4	XX	XX	24.2	0.0	0.0	0.0	14.4	9.8
4/10/12		XX	XX	68.3	14.2	0.0	51.3	2.8	XX	XX	51.5	0.0	0.0	0.0	26.7	24.8
7/10/12		XX	XX	82.4	18.8	0.0	57.9	5.7	XX	XX	39.7	0.0	0.0	1.2	22.6	15.9
10/9/12		131	67	77.4	16.2	0.0	56.5	4.7	125	30	6.0	0.0	0.0	0.0	0.0	0.0
1/8/13		92	67	40.4	8.0	0.0	31.0	1.4	143	33	34.6	0.0	0.0	0.0	19.1	15.5
4/9/13		120	59	35.0	9.3	0.0	22.5	3.2	160	28	30.7	0.0	3.8	1.2	15.7	10.0
7/9/13		167	46	30.0	4.4	0.0	24.9	0.7	169	29	43.4	0.0	0.0	0.0	16.9	26.5
10/8/13		215	48	86.2	14.2	0.0	68.8	3.2	131	36	33.7	0.0	0.0	0.0	17.1	16.6
1/14/14		169	45	27.4	6.8	0.0	18.3	2.3	132	34	27.5	0.0	0.0	1.0	16.6	9.9
4/8/14		176	45	35.8	6.3	0.0	28.0	1.5	135	33	28.0	0.0	0.0	0.0	18.0	10.0
7/8/14		171	67	120.2	17.1	0.0	101.0	2.1	151	37	56.9	0.0	0.0	0.0	13.8	43.1
10/14/14		137	73	108.5	16.5	0.0	89.4	2.6	128	40	47.7	0.0	0.0	0.0	15.0	32.7
1/13/15		56	71	18.9	5.4	0.0	12.0	1.5	107	44	45.0	0.0	0.0	0.0	31.0	14.0
4/13/15		72	69	27.4	6.7	0.0	19.1	1.6	90	53	63.3	0.0	5.1	0.0	38.7	19.5
#REF!		165	56	68.5	10.0	0.0	57.1	1.4	84	50	43.5	0.0	0.0	0.0	13.2	30.3
#REF!		205	46	69.2	15.7	0.0	49.7	3.8	88	44	23.7	0.0	0.0	0.0	10.4	13.3
#REF!		155		0.0					110		0.0					

Appendix C – *Excel Solver and Matlab Code*

Coefficients Optimization

Cl_o 3

R 0.748669

u 0.02045

T 16.35378

			From Model	From Data		From Calculation		NSSE	
Location	**Node**	**Index**	**Water Age (Time)**	**Cl (mg/L)**	**THM(μg/L)**	**Cl (mg/L)**	**THM(μg/L)**	**Cl**	**THM**
DS206	J24814	9693	104.1269	0.7075	35.1	0.8277	35.526	0.028851	0.0001
DS207	J36278	11697	129.7716	0.9133	37.1	0.7959	36.045	0.016515	0.0008
DS212	J41572	12549	376.7106	0.7125	35.8	0.7542	36.727	0.003433	0.0007
DS202	J55958	15071	124.2189	0.86	37.4	0.8013	35.957	0.00466	0.0015
DS205	J56656	15219	233.7578	0.7375	34.1	0.7588	36.653	0.000831	0.0056
DS209	J73654	21445	97.4265	0.8225	37.2	0.8397	35.329	0.000439	0.0025
DS203	J86024	26406	109.1758	0.984	35.9	0.8198	35.654	0.027841	0.0000
						SUM NSSE=		0.08257	0.0113
						Total NSSE=		0.093866	

Microsoft Excel 15.0 Answer Report
Worksheet: [Coefficient Optimization Data.xlsx]Sheet1
Report Created: 4/17/2016 3:09:38 PM
Result: Solver cannot improve the current solution. All Constraints are satisfied.
Solver Engine
Solver Options

Objective Cell (Min)

Cell	Name	Original Value	Final Value
I19	Total NSSE= Cl	0.093865572	0.093865572

Variable Cells

Cell	Name	Original Value	Final Value	Integer
B3	R	0.748669138	0.748669138	Contin
B4	u	0.02045016	0.02045016	Contin
B5	T	16.35378176	16.35378176	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
B3	R	0.748669138	B3<=1	Not Binding	0.251330862
B3	R	0.748669138	B3>=0	Not Binding	0.748669138
B4	u	0.02045016	B4<=1	Not Binding	0.97954984
B4	u	0.02045016	B4>=0	Not Binding	0.02045016
B5	T	16.35378176	B5<=100	Not Binding	83.64621824
B5	T	16.35378176	B5>=0	Not Binding	16.35378176

Microsoft Excel 15.0 Population Report
Worksheet: [Coefficient Optimization Data.xlsx]Sheet1
Report Created: 4/17/2016 3:09:38 PM

Variable Cells

Cell	Name	Best Value	Mean Value	Standard Deviation	Maximum Value	Minimum Value
B3	R	0.748669138	0.75842444	0.055097938	0.965993456	0.615576651
B4	u	0.02045016	0.027345287	0.062634516	0.550103652	0.000325743
B5	T	16.35378176	18.03557666	10.94390461	91.8539538	1.61728287

Constraints

NONE

Coefficients Optimization

Cl_o 2.1 mg/L

R 0.748669 (dimensionless)

u 0.02045 h^{-1}

T 14.25239 µg/L THM per mg/L consumed

			From Model	2014 Data	2015 Data	From Calculation		NSSE	
Location	**Node**	**Index**	**Water Age (Time)**	**Cl (mg/L)**	**THM(µg/L)**	**Cl (mg/L)**	**THM(µg/L)**	**Cl**	**THM**
DS206	J24814	9693	104.1269	0.7075	16.4	0.5794	21.673	0.032797	0.1034
DS207	J36278	11697	129.7716	0.9133	24.7	0.5572	21.989	0.152067	0.0120
DS212	J41572	12549	376.7106	0.7125	27.4	0.5280	22.405	0.067073	0.0332
DS202	J55958	15071	124.2189	0.86	22.7	0.5609	21.936	0.120956	0.0011
DS205	J56656	15219	233.7578	0.7375	27.2	0.5311	22.360	0.0783	0.0317
DS209	J73654	21445	97.4265	0.8225	20.6	0.5878	21.552	0.081419	0.0021
DS203	J86024	26406	109.1758	0.984	22.9	0.5739	21.751	0.173721	0.0025
							SUM NSSE=	0.706333	0.1861
							Total NSSE=	0.89242	

```
%%Matlab code to return indices of epanet model nodes.

%Load epanet library.
loadlibrary('epanet2', 'epanet2');

%Open the hydraulic model file.
calllib('epanet2', 'ENopen','Akron_Model.inp','akron.rpt','');

%Get node indices.
index=int32(0);
node='J86024';
[errcode, node, index]=calllib('epanet2','ENgetnodeindex',node,index);
```

```
%%Run hydraulic and water quality model to extract water age data for nodes of interest.

disp('Start environment')
fclose all;close all;
clc;
clear all;
clear class;

%Load library.
loadlibrary('epanet2', 'epanet2');

%Open the model.
calllib('epanet2', 'ENopen','Akron_Model.inp','akron.rpt','');

%Set quality type in model to "age".
    %The following is the format.
    %[errcode]=calllib(ENDLLNAME,'ENsetqualtype',qualcode,chemname,chemunits,tracenode);
    %qualcode=2 for water age
calllib('epanet2','ENsetqualtype',2,' ',' ',' ');

%Run model hydraulics.
calllib('epanet2','ENsolveH');

%Run water quality and end the loop at the time of interest.
t = 0;
tleft = 1;
index = [9693 11697 12549 15071 15219 21445 26406];
Nindex = length(index);
age(1,Nindex)=0;

calllib('epanet2','ENopenQ');
calllib('epanet2','ENinitQ',0);
while tleft > 0
[err, t] = calllib('epanet2','ENrunQ',t);
[err2, tleft] = calllib('epanet2','ENstepQ', tleft);
    if tleft <= 77400
        break
    end
end

%Extract water age data for nodes of interest.
for i = 1:Nindex
    [error, age(i)] = calllib('epanet2','ENgetnodevalue',index(i), 12, age(i));
end



disp('End of Simulation')
```

```
%%Calculate chlorine residual and THM formation for nodes of interest.

% Solve for Chlorine residual.
Cl_initial = (1:0.1:4);%Vary chlorine dose.
R = 0.748669;
u = 0.02045;
T = 16.35378; %R, u, and T from model calibration (excel solver).
t = evalin('base', 'age'); %Imports water age from previous script as the variable t.

Nt = length(t);
NCl_initial = length(Cl_initial);
Clt = zeros(Nt, NCl_initial);

for j = 1:NCl_initial
    for i = 1:Nt
        Clt(i, j) = [Cl_initial(j)*(1-R)/(1-R*exp(-u*t(i)))];
    end
end

%Solve for THM formation.
THM = zeros(Nt, NCl_initial);
Cl_initial2 = repmat(Cl_initial, 7, 1);

THM = T*(Cl_initial2-Clt);

%Fix Chlorine dose at 4mg/L and vary T to analyze effect on THM formation.
Cl_initial3 = 4;
T2 = (4:4:32);

Clt2 = zeros(1, Nt);

 for k = 1:Nt
    Clt2(k) = [Cl_initial3*(1-R)/(1-R*exp(-u*t(k)))];
 end

NClt2 = length(Clt2);
NT2 = length(T2);
THM2 = zeros(NClt2, NT2);

for l = 1:NClt2
    for m = 1:NT2
        THM2(l, m) = T2(m)*(Cl_initial3-Clt2(l));
    end
end

%Export data to file for data visualization in excel.
filename = 'Matlab_Results.xlsx';
xlswrite(filename, Cl_initial, 1, 'A3');
xlswrite(filename, THM, 1, 'A4');
```

```
xlswrite(filename, Cl_initial, 2, 'A3');
xlswrite(filename, Clt, 2, 'A4');
xlswrite(filename, T2, 3, 'A3');
xlswrite(filename, THM2, 3, 'A4');



disp('End of Simulation')
```

```
%%Matlab code to analyze effect of sampling time on Chlorine residual and
%%THM formation.

disp('Start environment')
fclose all;close all;
clc;
clear all;
clear class;

%Load epanet library.
loadlibrary('epanet2', 'epanet2');

%Open the hydraulic model file.
calllib('epanet2', 'ENopen','Akron_Model.inp','akron.rpt','');

%Get node index.
index=0;
node='J41572';%Enter epanet node name
[errcode, node, index]=calllib('epanet2','ENgetnodeindex',node,index);

%Set quality type in model to "age".
    %The following is the format.
    %[errcode]=calllib(ENDLLNAME,'ENsetqualtype',qualcode,chemname,chemunits,tracenode);
    %qualcode=2 for water age
calllib('epanet2','ENsetqualtype',2,' ',' ',' ');

%Run model hydraulics.
calllib('epanet2','ENsolveH');

%Run water quality and extract water age for sampling times of a standard work day (8am -↙
5pm) at 1 hour increments.
t = 0;
tleft = 1;
age8 = 0;
age9 = 0;
age10 = 0;
age11 = 0;
age12 = 0;
age13 = 0;
age14 = 0;
age15 = 0;
age16 = 0;
age17 = 0;

calllib('epanet2','ENopenQ');
calllib('epanet2','ENinitQ',0);
while tleft > 0
[err, t] = calllib('epanet2','ENrunQ',t);
[err2, tleft] = calllib('epanet2','ENstepQ', tleft);
```

```
    if tleft == 84600
        [error, age8] = calllib('epanet2','ENgetnodevalue',index, 12, age8);
    end
    if tleft == 81000
        [error, age9] = calllib('epanet2','ENgetnodevalue',index, 12, age9);
    end
     if tleft == 77400
        [error, age10] = calllib('epanet2','ENgetnodevalue',index, 12, age10);
     end
    if tleft == 73800
        [error, age11] = calllib('epanet2','ENgetnodevalue',index, 12, age11);
    end
    if tleft == 70200
        [error, age12] = calllib('epanet2','ENgetnodevalue',index, 12, age12);
    end
    if tleft == 66600
        [error, age13] = calllib('epanet2','ENgetnodevalue',index, 12, age13);
    end
    if tleft == 63000
        [error, age14] = calllib('epanet2','ENgetnodevalue',index, 12, age14);
    end
    if tleft == 59400
        [error, age15] = calllib('epanet2','ENgetnodevalue',index, 12, age15);
    end
    if tleft == 55800
        [error, age16] = calllib('epanet2','ENgetnodevalue',index, 12, age16);
    end
    if tleft == 52200
        [error, age17] = calllib('epanet2','ENgetnodevalue',index, 12, age17);
    end
end

ageT = [age8 age9 age10 age11 age12 age13 age14 age15 age16 age17];
```

```
%%Calculate chlorine residual and THM formation for nodes of interest.

% Solve for Chlorine residual.
Cl_initial = 4;
R = 0.748669;
u = 0.02045;
T = 16.35378; %R, u, and T from model calibration (excel solver).
t = evalin('base', 'ageT'); %Imports water age from previous script as the variable t.

Nt = length(t);
Clt = zeros(1, Nt);

for i = 1:Nt
    Clt(1, i) = [Cl_initial*(1-R)/(1-R*exp(-u*t(i)))];
end

% Solve for THM formation.
THM = zeros(1, Nt);
Cl_initial2 = repmat(Cl_initial, 1, 10);

THM = T*(Cl_initial2-Clt);

% Export data to file for data visualization in excel.
filename = 'Matlab_Results.xlsx';
xlswrite(filename, t, 5, 'A3');
xlswrite(filename, Clt, 5, 'A4');
xlswrite(filename, t, 6, 'A3');
xlswrite(filename, THM, 6, 'A4');


% disp('End of Simulation')
```

```
% Matlab code to create an overview of the Epanet model.

disp('Start environment')
fclose all;close all;
clc;
clear all;
clear class;

%Load library.
loadlibrary('epanet2', 'epanet2');

%Open the model.
calllib('epanet2', 'ENopen','Akron_Model.inp','akron.rpt','');

%Count number of nodes.
nodes = int32(0);
nodes_count = libpointer('int32Ptr',nodes);
[errorcode, nodes_count] = calllib('epanet2','ENgetcount',0,nodes_count);

%Count number of links.
links = int32(0);
link_count = libpointer('int32Ptr',links);
[errorcode, link_count] = calllib('epanet2','ENgetcount',2,link_count);

%Count number of tanks and reserviors.
tanks = int32(0);
tank_count = libpointer('int32Ptr',tanks);
[errorcode, tank_count] = calllib('epanet2','ENgetcount',1,tank_count);
```

```
%%Calculate chlorine residual and THM formation for nodes of interest.

% Solve for Chlorine residual.
Cl_initial = (1:0.1:4);%Vary chlorine dose.
R = 0.748669;
u = 0.02045;
T = 16.35378; %R, u, and T from model calibration (excel solver).
t = evalin('base', 'age'); %Imports water age from previous script as the variable t.

Nt = length(t);
NCl_initial = length(Cl_initial);
Clt = zeros(Nt, NCl_initial);

for j = 1:NCl_initial
    for i = 1:Nt
        Clt(i, j) = [Cl_initial(j)*(1-R)/(1-R*exp(-u*t(i)))];
    end
end

%Solve for THM formation.
THM = zeros(Nt, NCl_initial);
Cl_initial2 = repmat(Cl_initial, 7, 1);

THM = T*(Cl_initial2-Clt);

%Fix Chlorine dose at 2mg/L and vary T to analyze effect on THM formation.
Cl_initial3 = 2;
T2 = (4:4:32);

Clt2 = zeros(1, Nt);

 for k = 1:Nt
    Clt2(k) = [Cl_initial3*(1-R)/(1-R*exp(-u*t(k)))];
 end

NClt2 = length(Clt2);
NT2 = length(T2);
THM2 = zeros(NClt2, NT2);

for l = 1:NClt2
    for m = 1:NT2
        THM2(l, m) = T2(m)*(Cl_initial3-Clt2(l));
    end
end

%Fix Chlorine dose at 3mg/L and vary T to analyze effect on THM formation.
Cl_initial4 = 3;
T3 = (4:4:32);
```

```
Clt2 = zeros(1, Nt);

 for k = 1:Nt
    Clt2(k) = [Cl_initial4*(1-R)/(1-R*exp(-u*t(k)))];
 end

NClt2 = length(Clt2);
NT3 = length(T3);
THM3 = zeros(NClt2, NT3);

for l = 1:NClt2
    for m = 1:NT3
        THM3(l, m) = T3(m)*(Cl_initial4-Clt2(l));
    end
end

%Fix Chlorine dose at 4mg/L and vary T to analyze effect on THM formation.
Cl_initial5 = 4;
T4 = (4:4:32);

Clt2 = zeros(1, Nt);

 for k = 1:Nt
    Clt2(k) = [Cl_initial5*(1-R)/(1-R*exp(-u*t(k)))];
 end

NClt2 = length(Clt2);
NT4 = length(T4);
THM4 = zeros(NClt2, NT4);

for l = 1:NClt2
    for m = 1:NT4
        THM4(l, m) = T4(m)*(Cl_initial5-Clt2(l));
    end
end

%Export data to file for data visualization in excel.
filename = 'Matlab_Results2.xlsx';
xlswrite(filename, T2, 1, 'A3');
xlswrite(filename, THM2, 1, 'A4');
xlswrite(filename, T3, 2, 'A3');
xlswrite(filename, THM3, 2, 'A4');
xlswrite(filename, T4, 3, 'A3');
xlswrite(filename, THM4, 3, 'A4');



disp('End of Simulation')
```

Appendix D – Matlab/Epanet Integration Manual for Windows 7 and Windows 10 Operating Systems

Table of Contents

Matlab/EPANET Download and Configuration

The following are instructions to install Matlab and corresponding components in order to run and manipulate EPANET input files. These instructions are for Windows 64 or 32-bit machines and include instructions for Window 7 and Windows 10 operating systems.

Window 7 Setup

Step 1: Download and install the latest version of matlab.

Step 2: Choose a supported compiler for your version of Matlab from the MathWorks website.

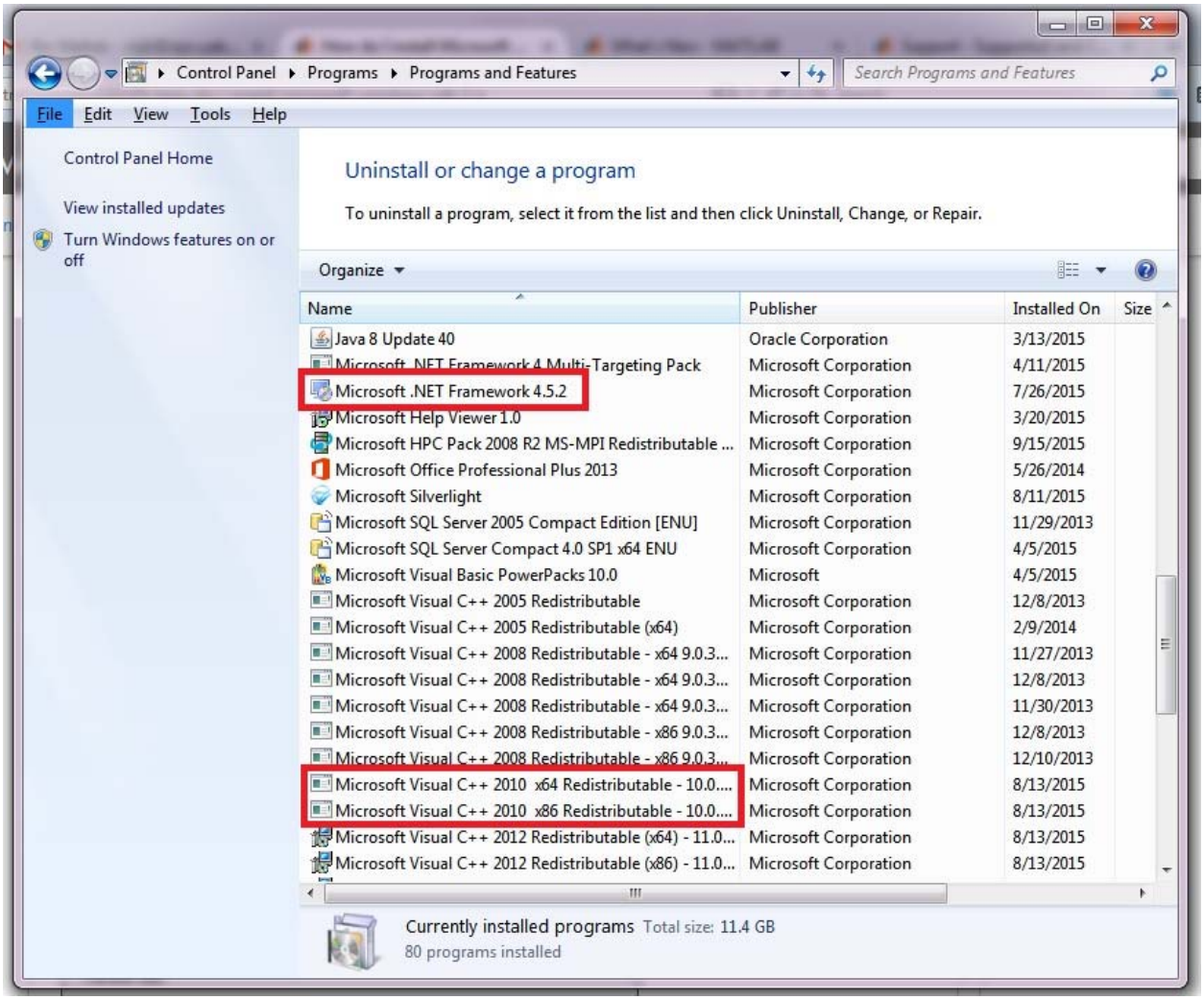
MATLAB Product Family – Release 2015b

Compiler	MATLAB	MATLAB Compiler	MATLAB Compiler SDK				MATLAB Coder	SimBiology	Fixed-Point Designer	HDL Coder	HDL Verifier
	For MEX-file compilation, `loadlibrary`, and external usage of MATLAB Engine and MAT-file APIs	*Excel add-in for desktop*	*C/C++*	*.NET*	*Java*	*Excel add-in for MPS*	*For all features*	*For accelerated computation*	*For accelerated computation*	*For accelerated testbench simulation*	*For DPI and TLM component generation*
MinGW 4.9.2 (Distributor: TDM-GCC) *Available at no charge*	✓						✓	✓	✓	✓	✓
Microsoft Windows SDK 7.1 *Available at no charge; requires .NET Framework 4.0*	✓	✓	✓				✓ 6	✓	✓	✓	✓
Microsoft Visual C++ 2015 Professional	✓	✓	✓	✓	✓	✓					

Step 3: Install selected compiler. (Microsoft Windows SDK 7.1 is the recommended compiler) Before installing Microsoft Windows SDK 7.1 check to see if the following applications are already on your machine:

- .NET Framework 4.5
- Microsoft Visual Studio C++ 2010 SP1

If either of those applications are installed on the machine see the troubleshooting section of these instructions.



Step 4: Download Windows SDK for Windows 7 and .NET Framework 4 from Microsoft at:

http://www.microsoft.com/en-us/download/details.aspx?id=8279

Step 5: When the download is complete, choose to run winsdk_web.exe (do not save) when prompted. Follow the setup wizard, but do not change any of the defaults or installation folder locations.

Windows 10 Setup

Step 1: Download and install the latest version of matlab.

Step 2: Choose a supported compiler for your version of Matlab from the MathWorks website.

MATLAB Product Family – Release 2015b

Compiler	MATLAB *For MEX-file compilation, `loadlibrary`, and external usage of MATLAB Engine and MAT-file APIs*	MATLAB Compiler *Excel add-in for desktop*	MATLAB Compiler SDK *C/C++*	 *.NET*	 *Java*	 *Excel add-in for MPS*	MATLAB Coder *For all features*	SimBiology *For accelerated computation*	Fixed-Point Designer *For accelerated computation*	HDL Coder *For accelerated testbench simulation*	HDL Verifier *For DPI and TLM component generation*
MinGW 4.9.2 (Distributor: TDM-GCC) *Available at no charge*	✓						✓	✓	✓	✓	✓
Microsoft Windows SDK 7.1 *Available at no charge; requires .NET Framework 4.0*	✓	✓	✓				✓ 6	✓	✓	✓	✓
Microsoft Visual C++ 2015 Professional	✓	✓	✓	✓	✓	✓					

Step 3: Install selected compiler (MinGW 4.9.2 is the recommended compiler).

- For installation instructions, open Matlab.
- Navigate to the Home ribbon and click on Help.
- Type MinGW in the search bar.
- Follow the instructions for installation.

Troubleshooting

.NET Framework 4.5 already installed:

1. Uninstall .NET Framework 4.5.
2. Continue with the instructions to install SDK 7.1 (above).
3. Reinstall .NET Framework 4.5.

Microsoft Visual Studio C++ 2010 SP1 already installed:

1. Uninstall all versions of Microsoft Visual Studio C++ 2010.
2. Continue with the instructions to install SDK 7.1 (above).
3. Download and install the SDK 7.1 patch from:

   http://www.microsoft.com/en-us/download/details.aspx?displaylang=en&id=4422

4. Reinstall 2010 Redistributable packages.