# Flint's Path From Crisis to Distribution System Optimization

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The water crisis in Flint, Mich., was triggered in April 2014 as a result of a change from purchased treated water from the Detroit Water and Sewerage Department (DWSD) to the Flint River, using the existing City of Flint (city) water treatment plant (WTP). The switch resulted in a number of distribution system issues, including Total Coliform Rule (TCR) violations, boil-water orders, main breaks, disinfection byproduct (DBP) issues, *Legionella* outbreaks, and elevated lead levels. In response to the crisis, the city, with support from the Michigan Department of Environmental Quality (MDEQ) and the U.S. Environmental Protection Agency (EPA), implemented new programs, practices, and treatment, including the addition of a corrosion control inhibitor, to restore the quality of the water and to protect public health.

The city developed a distribution system optimization plan to restore customer confidence and enhance its water distribution system operation and maintenance (O&M) practices. The planning process included an assessment of current distribution system practices and corrosion control treatment compared to industry best practices, the identification of associated gaps, and a determination of the human and financial resources needed to implement the recommended prioritized list of improvements for the city.

## History

### Water Supply

In November 2011, the city was brought under control of an emergency manager following accumulation of nearly $26 million in deficits. Under the advice of the emergency manager and other Michigan officials, the Flint City Council voted to purchase water from Karegnondi Water Authority (KWA) in a cost-saving move away from DWSD. The KWA was intending to construct an 80-mi pipeline (60 and 66 in. in diameter) to provide and distribute water from Lake Huron to Flint and other communities in Genesee, Lapeer, and Sanilac counties.

In April 2013, DWSD asked the city to reconsider its decision to purchase water from KWA. When the city failed to do so, DWSD sent a notice of termination effective in April 2014. Construction of the KWA pipeline was not to begin until June 2013, which meant the city had to find an alternative supply until the KWA pipeline was completed.

In June 2013, the emergency manager approved plans to treat Flint River water at the city's WTP. The Flint River and WTP were previously considered an emergency supply and had not been used for decades. On April 1, 2014, MDEQ approved a construction permit for improvements to the WTP. Less than one month later, on April 25, the city switched to the Flint River and remained on that supply until Oct. 16, 2015, at which time it switched back to the Detroit supply following the well-publicized water quality crisis.

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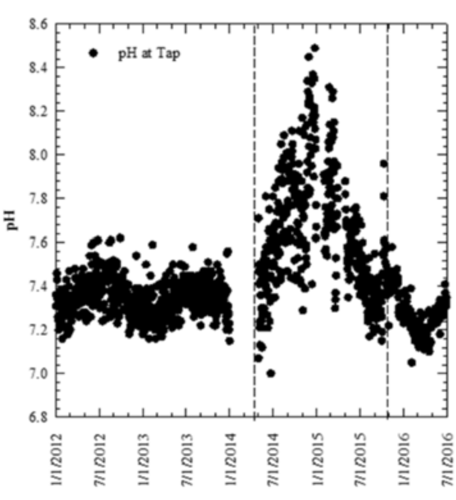
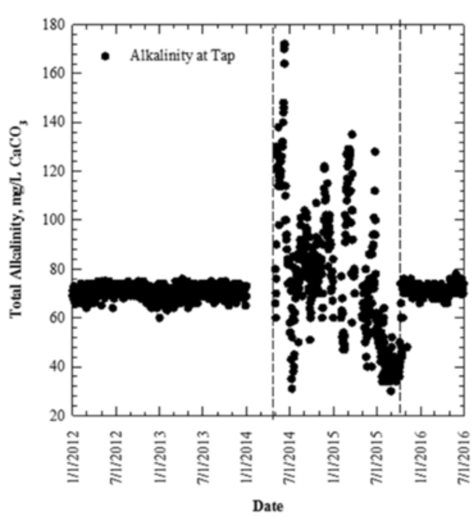
### Water Quality

For decades, DWSD provided the city with treated water from Lake Huron, which was a stable and consistent source from a water quality perspective. This is essential to maintaining distribution system water quality, including maintaining effective corrosion control treatment, maintenance of a disinfectant residual, and control of DBPs.

Figures 1 and 2 show plant tap pH and alkalinity prior to, during, and following discontinuation of use of Flint River water. As is shown in the figures, treated pH and alkalinity were widely variable during the period when Flint River was used as a supply. This is attributed to the variability of the Flint River as a source and the lack of proper treatment at the WTP to address the variability. Because of the variability, the city experienced a number of well-publicized water quality problems:

- In August and September 2014, boil-water advisories were issued due to the presence of *E. coli* and coliform bacteria. The city boosted the distribution system chlorine residual and increased flushing as a result.
- In November 2014, the city first exceeded the maximum contaminant level (MCL) for total trihalomethanes. This problem persisted until August 2015.
- In January 2015, residents show up at city council meetings with bottles of discolored water, and complained that their water "tastes funny and smells terrible."
- In February 2015, the first incidence of high lead is observed following sampling in one home, prompted by rashes on a child. The EPA Region V called the results "alarming" and




Figures 1 (left) and 2 (right). pH and Alkalinity at the Flint Water Treatment Plant Tap *(Source: EPA)*

- MDEQ responded by saying that the city had an optimized corrosion control program.
- In March 2015, EPA raised more concerns with MDEQ, suspecting that lead service lines were the sources of increased lead concentrations. Also, the Genesee County Health Department observed an increase in local cases of Legionnaire's disease, including in Flint. The EPA questioned whether it could be related to the ongoing water quality problems in Flint.
- In April 2015, MDEQ stated that Flint had no corrosion control in place, but it was not required based on Lead and Copper Rule (LCR) monitoring results. In June, EPA said that, in light of lead test results, a lack of corrosion control treatment was a major concern.
- In August 2015, Virginia Polytechnic and State University (Virginia Tech) began a study of Flint water quality and in September 2015 stated that the water was corrosive and caused lead to leach into residents' water.
- On Sept. 24, 2015, an increase in blood lead levels was observed in the children of Flint.
- On Sept. 25, 2015, a lead advisory was issued stating that only cold water should be used for drinking and making infant formula.
- On Oct. 1, 2015, the Michigan Department of Health and Human Services (DHHS) and the Genesee County Health Department declared a public health emergency. The city and the health department urged customers to not drink the water.
- On Oct. 8, 2015, the decision was made to switch back to Detroit water, operating as Great Lakes Water Authority (GLWA), and the city switched back to GLWA water on Oct. 16, 2015.

Treated water from GLWA contained an orthophosphate residual of approximately 1 mg/L as phosphorus and had a pH of approximately 7.5. To re-establish corrosion control treatment in the city's distribution system, EPA directed the city to boost the orthophosphate residual to maintain a minimum 3.1 mg/L residual throughout the distribution system, boost the chlorine residual (using sodium hypochlorite) sufficiently to maintain compliance with the TCR, and maintain treated water pH greater than 7. The city targeted 7.5 ± 0.2 units using caustic soda.

As of March 31, 2017, city residents were advised that Flint water was safe for bathing, but they should utilize a water filter for water used for drinking and cooking. As of this writing, filters and bottled water are still provided by the State of Michigan.

Table 1. Distribution System Characteristics

| Item | Description |
|---|---|
| Pipe Diameter | • 52 percent as 6-in. pipe (~300 mi)<br>• 24 percent as 8-in. pipe (~138 mi)<br>• 8 percent as 12-in. pipe (~47 mi)<br>• 16 percent of remaining pipe ranges from 2 to 72 in. (~98 mi) |
| Pipe Material | • 96.6 percent is unlined cast iron pipe (564 mi)<br>• 2.6 percent is ductile iron (31 mi)<br>• Remaining material includes steel, concrete, galvanized, and unidentified |
| Pipe Age | • 63 percent installed between 1900 and 1930<br>• 33 percent installed between 1930 and 1960<br>• 4 percent installed after 1960 |

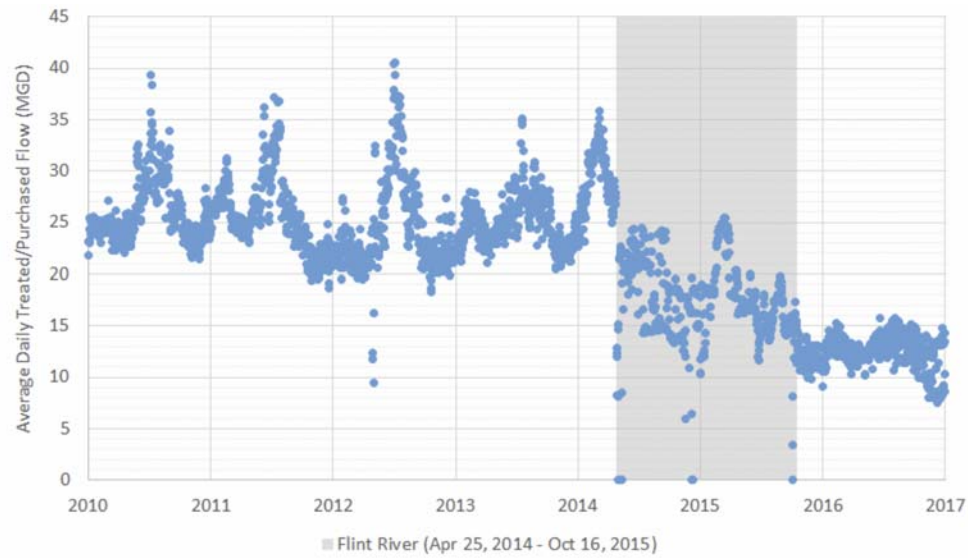



Figure 3. Historic Water Demands

## Water System Overview

### Water Distribution System

The city's distribution system includes two storage facilities: the Cedar Street Reservoir, which was constructed in 1948 and expanded in the 1960s and has a total capacity of 20 mil gal (MG); and the West Side Reservoir, which was constructed in 1970 and has a capacity of 12 MG. Both facilities have the ability to boost chlorine on the fill line to the reservoir using liquid sodium hypochlorite.

In addition to the distribution storage, the city has 25 MG of available storage at the WTP, for a total of 57 MG. The city began practicing deep cycling of its reservoirs to manage water age in the distribution lines. Due to the high number of main breaks in the system, city staff was generally uncomfortable with scaling down the amount of storage regularly used in the distribution system.

The Flint distribution system has approximately 580 mi of pipe, with its characteristics shown in Table 1.

### Water Demand

The population of Flint has dropped significantly since its peak in the 1960s. It has experienced a 20 percent decrease in population since 2000 and has a current estimated population of 98,310. This decline has left the water department with an oversized distribution system, creating physical, hydraulic, and water quality challenges, including water age and chlorine residual management.

Prior to the water crisis, system demand averaged 25.5 mil gal per day (mgd) from 2010 to 2013. During the crisis, demand dropped to 17.6 mgd, and has hovered near 13 mgd since

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the system reconnected to GLWA (Figure 3). Contributing to the decline in demand was the loss in October 2014 of General Motors, a commercial customer, over water quality concerns. As the water system stabilizes and water quality concerns decrease, demand may increase; however, given continuing decreasing population trends, demand may not return to pre-crisis levels.

## Criteria for Optimized Distribution Systems

The American Water Works Association (AWWA) Partnership for Safe Water distribution system optimization program is comprised of a methodology for utilities to optimize their distribution systems through a phased process of commitment to the program, annual data reporting to the partnership, self-assessment, and optimization. Although the partnership recognizes that it is difficult for any utility to achieve fully optimized status as defined by its performance goals, it offers a process in which all utilities can advance their system operations to attain performance nearer the goals. The city is utilizing the partnership methodology as the basis for optimizing its water distribution system.

The optimization program focused on three performance indicators discussed here.

*Water Quality Integrity.* The water quality indicator is based upon the capability of maintaining an adequate distribution system residual disinfectant level. An optimized distribution system using free chlorine as a secondary disinfectant will maintain the following:

- Chlorine residual of at least 0.20 mg/L and no greater than 4 mg/L in 95 percent of all routine monthly readings.
- Routine sample locations should include known problem areas and all storage facilities.
- No routine sample locations are to have consecutive readings outside this range.
- The DBPs meet regulatory limits for each sample tested (not based on a running annual average); specifically, every total trihalomethane sample is ≤ 80 micrograms per liter (µg/L) and every haloacetic acids five (HAA5) is ≤ 60 µg/L.

*Physical Integrity.* The physical soundness indicator is based upon the frequency of distribution system main breaks and leaks. Optimization of infrastructure integrity includes the goal of meeting the following criteria:

- No more than 15 reported main breaks and leaks per 100 mi of pipeline per year.
- Reducing main break and leak frequency (based upon a rolling, five-year trend).

*Hydraulic Integrity.* The hydraulic soundness indicator is based on pressure management through the distribution system. Pressure must be monitored continuously, from the sensor located within the distribution system, ideally at low- and high-pressure locations. The goal for pressure management includes the following:

- Distribution system pressure should be maintained at or above 20 pounds per sq in. (psi) in 99.5 percent of measurements (based on daily minimums from hourly readings).
- Maximum pressure does not exceed utility-specific maximum in 95 percent of measurements.
- Pressure should be met under normal conditions, including maximum day demand and fire flow conditions (excluding emergencies).
- Utilities have pre-approved procedures to protect public health during emergency conditions (main breaks, power outages).
- Utilities have predetermined goals for maximum pressure ranges (differences between minimum and maximum pressure) within each pressure zone.

Many other factors (administrative, design, maintenance, and operations) influence, or can be influenced by, these integrity performance indicators. Optimization through self-assessment of some or all of these factors (known as improvement variables) is another critical step in the program. Administrative factors, specifically administrative policies, funding, and staffing, were also reviewed, as they impact all aspects of a water utility, not just the distribution system.

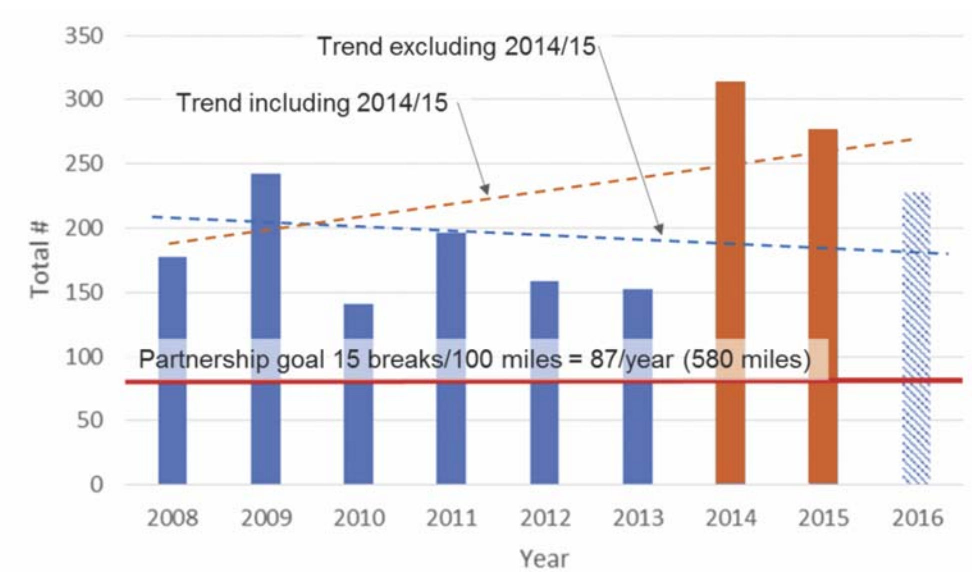

Figure 4. Main Breaks Per Year (2008–2016)

## Distribution System Assessment

**Water Main Break Analysis**

The analysis of main breaks falls under the guidance outlined in the partnership's physical integrity category. The objectives of this analysis were to compare city practices to the partnership goals and criteria, identify potential causes of main breaks and opportunities for improvement, and if possible, identify impacts of the switch to the Flint River on infrastructure integrity.

Figure 4 presents the number of main breaks per year for the period 2008 to 2016, and compares the number of breaks to the partnership goals. Excluding the data from years 2014 and 2015, the actual trend indicates a decrease in number over time; inclusion of the 2014 and 2015 breaks change the trend to be increasing over time. Currently, there is inconsistency with regard to the actual number of pipe miles in the Flint system, ranging somewhere between 580 and 800 mi. The optimization goal for 800 mi of pipe is 120 breaks per year, compared to 87 breaks per year for 580 mi. In either case, the city does not currently (nor historically) meet the optimization goal.

Figure 5 compares the occurrence of water main breaks to temperature. This trend shows both the breaks and the average (recorded at Bishop International Airport) for each month. The figure clearly shows that the peak number of breaks occur during cold weather months. The coldest sustained temperatures within the dataset occurred in the winter 2014 season (average median low of 11°F sustained for two months) prior to the switch to the Flint River. The coldest individual month occurred in February 2015. The warmest winter occurred in the 2015/2016 season and had one of the lowest rates of winter breaks per month (based on data available through January 2016). Based on this analysis, temperature played a more significant role in the number of breaks than the change in source water.

**Chlorine Residual**

Maintenance of a disinfectant residual is critical to ensuring the integrity of a distribution system. In addition to providing microbial control, disinfectant residuals provide oxidizing conditions to help stabilize pipe scales and can serve as an indicator of distribution system integrity. Therefore, a key aspect of distribution system water quality management and optimization is to identify appropriate disinfectant residual levels and strategies for monitoring and maintaining them on an ongoing basis.

Through 2016, the city monitored chlorine residual at the entry point daily and at 10 locations in the distribution system, including at the two main reservoirs. A minimum of 100 samples were collected and analyzed each month as part of routine regulatory TCR monitoring.

Figure 6 shows site-specific data during the three operational periods (before, during, and after the switch) for the city's original 10 TCR monitoring locations. Chlorine residual boosting began in January 2016 at the Cedar Street and Westside reservoirs and at the WTP in May 2016. As of June 2016, the city began targeting a free chlorine residual concentration of 1.7 mg/L leaving the plant.

Since September 2016, the city has maintained chlorine residual concentrations above 0.5 mg/L in 95 percent of samples collected throughout the distribution system. The 0.5 mg/L level, while greater than the partnership target of 0.2 mg/L in 95 percent of samples, is viewed as appropriate for Flint during the restabilization process and to assist with control of microbial growth beyond the customer's meter.

**Lead**

The most highly publicized aspect of the crisis was the elevated lead concentrations that resulted from the water source change, which caused one of the most intensive water quality investigations ever completed. In total, USEPA, MDEQ, and the city collected more than 29,000 lead samples at more than 15,000 homes.

The city has been in compliance with LCR since January 2017 when the reported 90th percentile lead concentration was 12 µg/L, compared to the action level (AL) of 15 µg/L; however, further analysis of the lead monitoring results from the extended monitoring conducted by EPA and MDEQ demonstrated the significant improvements that have been made since January 2016.

Figure 7 presents the first liter tap lead concentrations for 126 homes for which data were available for four quarters of monitoring in 2016. The data show that through the first half of 2016, more than 40 percent of the homes sampled had tap lead concentrations greater than the AL; by the end of 2016, less than 10 percent of homes exceeded the AL. The figure also shows the dramatic reduction in maximum lead concentrations in those homes.

The city remains focused on corrosion control and is beginning an extensive corrosion testing program to re-establishing optimizing corrosion control treatment. One of the primary objectives of the program will be to continue to reduce the maximum lead concentrations, with the goal of every home being less than the AL.

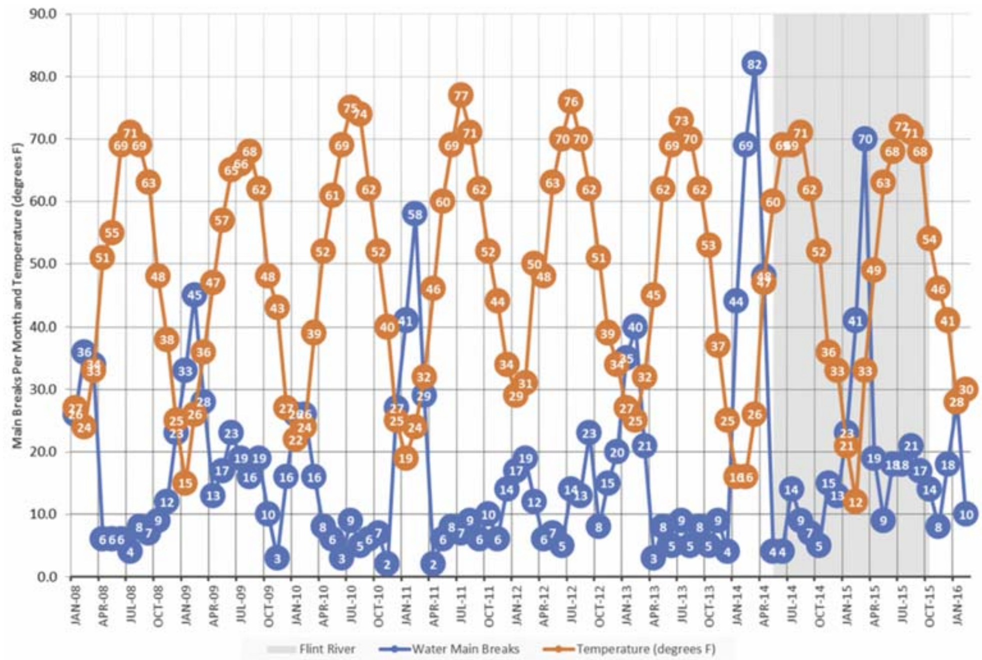


Figure 5. Comparison of Main Breaks and Ambient Temperature

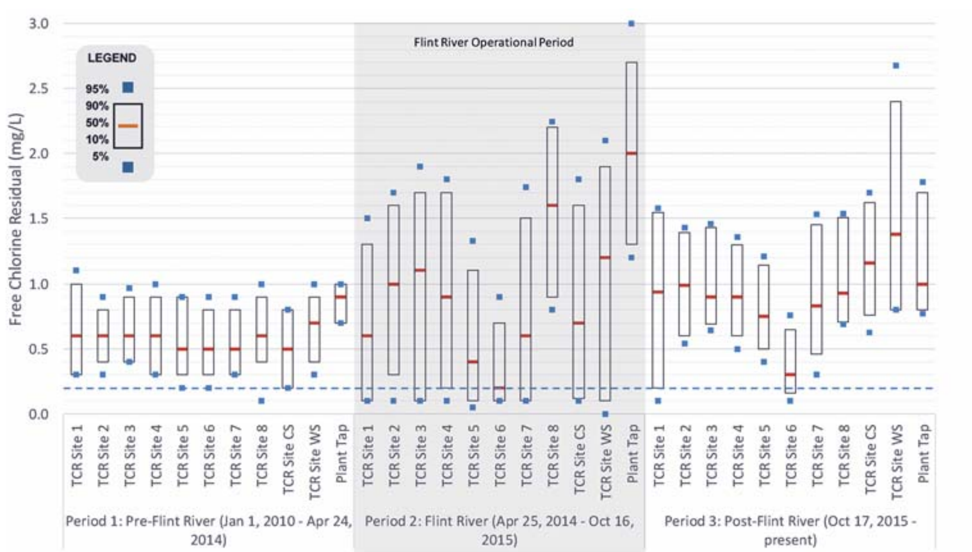


Figure 6. Free Chlorine Concentrations at Total Coliform Rule Sites

## A Path Forward

**Approach**

As was stated previously, the ability of the

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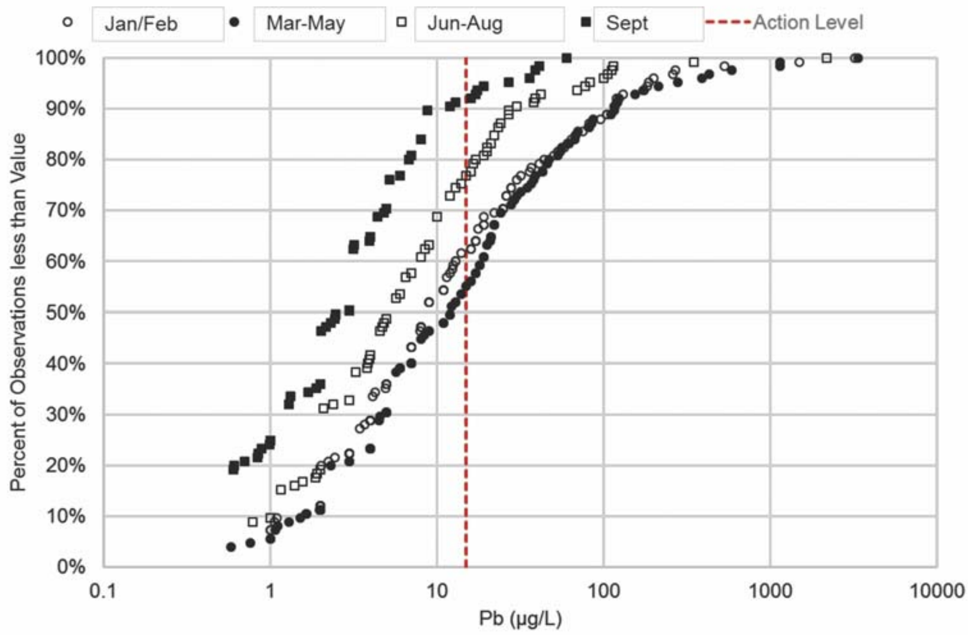


Figure 7. 2016 Maximum Lead Concentration by Season
(126 locations for which data were available for all four sampling events)

Table 2. Partnership for Safe Water Distribution System Improvement Variables Assessed

| Improvement Variable | Water Quality Integrity | Physical Integrity | Hydraulic Integrity |
|---|---|---|---|
| Cross-Connection Control | ✓ | | ✓ |
| Customer Complaint Tracking and Response | ✓ | ✓ | ✓ |
| Disinfection Byproduct Compliance | ✓ | | |
| Flushing | ✓ | ✓ | ✓ |
| Hydraulic Modelling | ✓ | ✓ | ✓ |
| Installation, O&M of Valves and Hydrants | ✓ | ✓ | ✓ |
| Internal Corrosion Control | ✓ | ✓ | |
| Online Monitoring | ✓ | | ✓ |
| Pipeline Installation, Rehabilitation and Replacement | | ✓ | ✓ |
| Post-Precipitation Control | ✓ | | ✓ |
| Pump Station Design, Operation and Maintenance | | ✓ | ✓ |
| Security and Emergency Management | ✓ | ✓ | ✓ |
| Storage Facility Design, Operation and Maintenance | ✓ | ✓ | ✓ |
| Water Age Management | ✓ | | |
| Water Loss Control | | ✓ | ✓ |
| Water Quality Sampling and Response | ✓ | | |

*(Source: adapted from Water Research Foundation Criteria for Optimized Distribution Systems, Friedman et al., 2010; and AWWA Partnership for Safe Water Self-Assessment Guide for Distribution System Optimization, AWWA, 2011)*

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city to meet the partnership goals is influenced by a number of factors. Optimization through self-assessment of some or all of these factors (known as improvement variables) is another critical step in the program. The improvement variables most relevant to the city are presented in Table 2.

**Findings and Recommendations**

The city is in the process of implementing a number of actions in its quest for distribution system optimization. Immediate recommendations focused on those that directly impact the city's ability to achieve compliance with current regulations or to minimize risks to public health over those that will achieve optimization, as outlined in the partnership program.

Beginning in 2017, the number of routine chlorine monitoring sites was increased to 20, and each will be monitored a minimum of five times each month. The city is targeting a goal of 25 routine coliform samples, so this program is anticipated to expand in the near future. In the meantime, chlorine residual readings are being collected from five additional surveillance monitoring locations each week to provide a combined total of 35 chlorine readings from 25 unique locations each week.

In addition, the following items are expected to be carried out in the short term:

- Implement surge control at reservoirs and pump stations, and conduct analysis of future WTP operations on distribution system pressures.
- Use hydraulic modeling to evaluate water age and opportunities for minimizing it.
- Site and install distribution system pressure data loggers to verify pressure control.
- Purchase and install online distribution system water quality monitoring panels. Prior to installation, use the hydraulic model to confirm optimal locations for installation.
- Develop and implement a distribution system operator training program.
- Develop and implement a unidirectional flushing program.
- Develop standard operating procedures for routine maintenance activities and for those activities that impact water quality (flushing, chlorine residual maintenance, etc.).
- Increase funding for main replacement activities.
- Conduct a local utility salary survey and adjust operator salaries as necessary to be competitive in the local market.
- Develop a hiring plan to fill vacant positions within the Water Service Center distribution department.
- Provide "whole house" flushing guidance to residents and encourage them to flush their

homes regularly until water quality within the home is restored.

While opportunities for improvement were identified for each variable, long-term actions focus on the following areas:

- Rehabilitation and replacement (R&R) of valves and hydrants.
- Pipeline R&R (exclusive of lead service lines that will be replaced entirely by 2020).
- Pump station improvements to reduce pressure surges and main breaks.
- Storage facility improvements to improve system reliability and water quality and reduce water age.
- System operational improvements to reduce water age and improve distributed water quality.

Next steps include development of a risk-based pipeline R&R program, prioritization and scheduling of optimization program recommendations, and creation of a capital improvement plan.

## Summary and Conclusions

As a result of a change in source water, the city experienced a well-publicized water quality crisis. It has emerged from the crisis with a well-thought-out plan to achieve distribution system optimization. The AWWA Partnership for Safe Water distribution system optimization program was utilized to develop the plan, and is an effective means for any utility to assess and improve operations of its water distribution system.

The city has taken a number of steps to improve distribution system water quality, including operational changes to reduce water age and chlorine and orthophosphate residual boosting. In addition, it has expanded distribution system water quality monitoring to evaluate changes in water quality throughout the distribution system and identify and respond to water quality upsets in a more proactive manner. As a result of these changes, there has been a marked improvement in the city's water, most notably, that it is in compliance with LCR, lead concentrations continue to decline, and free chlorine residuals have improved.

With all of the progress that has been made, there remains significant opportunity for improvement. The city continues to re-establish optimized corrosion control treatment and standard operating procedures are being reviewed and developed for valve and hydrant repair, pipeline maintenance, system operation, and water quality maintenance functions, such as flushing. Next steps include development of a risk-based pipeline R&R program, prioritization of long-term actions, and development of a capital improvement plan.

Though considerable effort remains, the city is on a path to distribution system optimization. Its plan will result in continued water quality improvements, improved water system reliability, and more effective operation and management of the water system. Though it will take time, these efforts will go a long way to restoring public and private trust in the city and its water supply, and improving the quality of life for Flint residents.

## References


- American Water Works Association (AWWA) (2011). "Partnership for Safe Water Self-Assessment Guide for Distribution System Optimization." AWWA, Denver, Colo.
- Friedman, M., Kirmeyer, G., Lemieux, J., LeChevallier, M., Seidl, S., and Routt, J. (2010). "Criteria for Optimized Distribution Systems." Water Research Foundation. Denver, Colo.