DISTRIBUTION SYSTEM OPTIMIZATION AT WATER SYSTEMS UTILIZING FREE CHLORINE AS THE PRIMARY OXIDANT

Sample Collection & Data Management

Bureau of Water Standards and Facility Regulation
Safe Drinking Water Program

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

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TABLE OF CONTENTS

Page Number

Acknowledgement

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INTRODUCTION

The vision of distribution optimization is to sustain the water quality leaving the plant throughout all points in the distribution system. Further, “optimization” refers to improving drinking water quality to the highest levels possible (which are normally more protective than those required by EPA and the State of Pennsylvania regulations) to enhance public health protection without the immediate need for significant capital improvements to the water treatment plant or distribution system infrastructure. Although, all water systems should plan and budget for capital improvements, as needed.

Optimization at the treatment level, specifically filtration plants, has been a focus of the drinking water industry since the 1980s. Optimization at a water treatment plant typically entails a performance assessment which incorporates ensuring data integrity, collecting proper data and trending the data. Ultimately, these assessments are used to make process control decisions as a system strives to achieve optimization. Data collection and analysis is one of the primary focuses, and starting point, of distribution optimization as well.

Why Optimize?

The distribution system is the last “barrier” for protecting public health, meaning the physical and chemical barriers that have been established are necessary to protect the public from intentional or unintentional exposure to contaminants after the water has been treated.

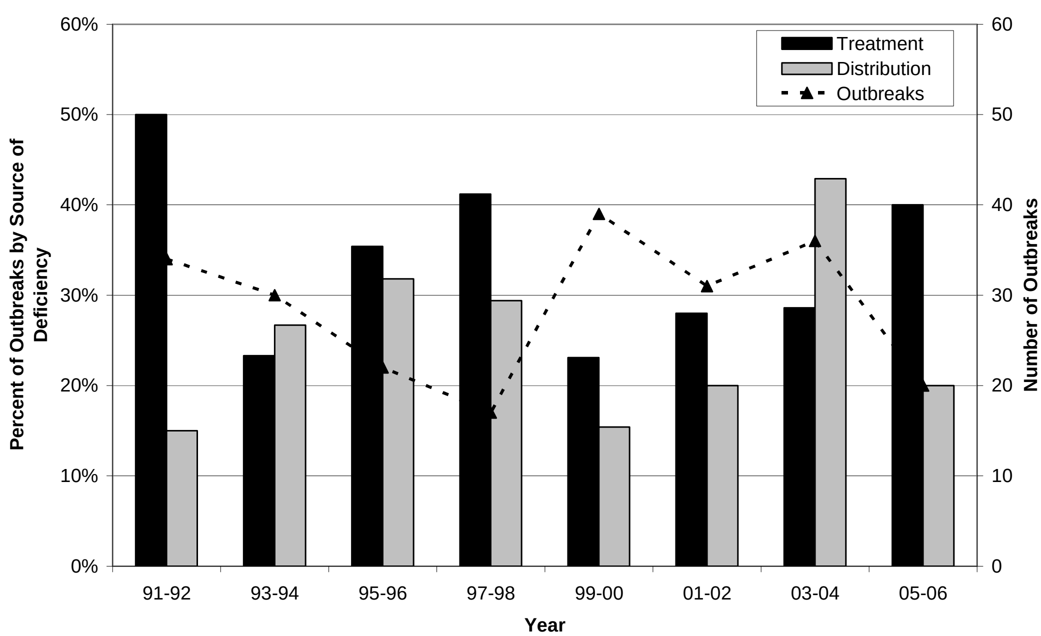
Distribution system optimization focuses on two primary health concerns related to water quality within the distribution system:

- Microbial contamination
- Disinfection By-Product (DBP) formation

Microbial Contamination

Distribution systems have been implicated in a significant percentage of waterborne disease outbreaks, as seen in Figure 1.[1]

Figure 1



[1] Centers for Disease Control and Prevention. (1991-2006). Surveillance for Waterborne Disease and Outbreaks Associated with Drinking Water and Water not Intended for Drinking. *Morbidity and Mortality Weekly Report*. Reports dated 1991-2006, as summarized by the US Environmental Protection Agency Technical Support Center, Cincinnati, OH.

These outbreaks are attributed to the breakdown in the distribution system physical or chemical barriers, or both. It is important to note that these statistics are based on *reported* outbreaks, which constitute two or more persons having been epidemiologically linked by location of exposure, time and illness. Many waterborne diseases may go untreated by a physician and are, therefore, unreported.

DBP Formation

The current regulated DBPs are Total Trihalomethanes (TTHMs), comprised of four species of trihalomethanes, and Haloacetic Acids (HAAs), comprised of five species of haloacetic acids. THMs and HAAs are, simply stated, a product of a reaction between a disinfectant (chlorine or monochloramine) and precursors (natural organic matter and bromide). The overall formation is affected by various parameters including concentration of precursors, disinfectant dose and residual, time, temperature and pH. Potential DBP related health concerns include suspected carcinogens (bladder cancer) and reproductive and developmental disorders.

Taking these factors into consideration, DBP formation is highly variable from drinking water system to system, even if source water characteristics are similar. Overall treatment techniques, treatment effectiveness and chemical dosages are factors affecting formation at a water treatment facility. Distribution system size, distribution system maintenance and water age are factors influencing formation in the distribution system.

Formation, of THMs and HAAs within the distribution system, is somewhat different. THMs will continue to increase as water age increases, as long as the precursors for formation are present. HAAs will increase until they reach a maximum formation potential, typically at a mid-point in the system, and then have the potential to decrease as water age increases due to biodegradation. Biological degradation typically occurs at high water age, low chlorine residual and warm water temperatures.

Distribution Optimization Approach

As stated earlier, optimization at a water treatment plant starts with three key data-related activities:

- ensuring data integrity
- collecting proper data
- trending the data

These are the same concepts that will be used to support optimization efforts within the drinking water distribution system.

Administrative Challenges

In addition to these data management activities, optimization requires administrative capabilities and management support that is not specifically covered in this document. The administrative and personnel aspects of water system operation are crucial to the proper and successful implementation of optimization activities.

It is necessary to ensure that the water system has the policies, staffing and funding to support optimization activities. In addition, without the commitment of management and personnel, optimization activities will most likely fail due to competing priorities, lack of motivation due to poor or nonexistent support, or lack of support for change, both operationally and financially.

It is therefore essential to get support and commitment from all levels of personnel prior to implementing optimization activities.

ENSURING DATA INTEGRITY

Data integrity will ensure that distribution system optimization efforts are accurate and effective. By ensuring consistent and accurate sampling and analysis, data will be comparable from location to location, data trending will be accurate and meaningful, and process control decisions will be better supported.

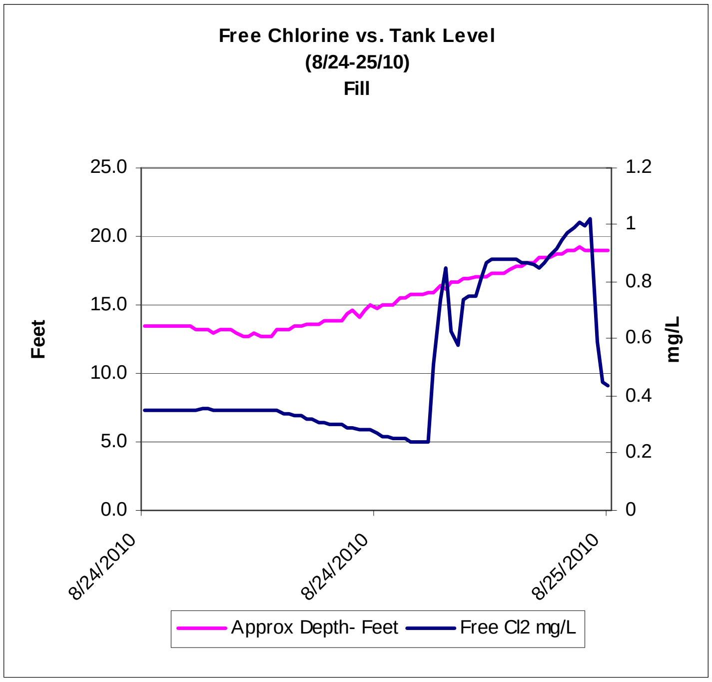
Although there are many factors that can impact data integrity, including but not limited to proper analytical equipment calibration and maintenance and following the correct analytical methods, the two elements of data integrity that will be covered in this document are:

- Sample timing
- Sampling technique

Sample Timing

Water quality within the distribution system varies spatially and temporally, which may impact sampling results greatly at a single location. For example, collecting a sample near the base of a tank at the end of the fill cycle may represent water of higher quality (e.g. greater chlorine residual) than collecting a sample at that same location near the end of a draw cycle. An example of continual water quality changes at a tank location over time is shown in Figure 2.

Figure 2



Ultimately, sample collection would be best conducted at a time that represents the “worst case scenario” and at a time that can be duplicated for each sampling event. If the optimization goals are being met during the “worst case scenario”, then the optimization goals should be met during all times of operation. For example, if a water plant operates 12 hours a day and the distribution system receives water from distribution storage for the other 12 hours, the “worst case scenario” would be prior to the start-up of the treatment plant since the distribution system would be most impacted by water that may have degraded during storage.

Determining a specific time for the “worst case scenario” may be unrealistic for most systems, as hydraulics (both supply and demand) change from day to day and throughout any given year. Therefore, while collecting and analyzing data, it is important to understand that water quality is going to change at any given location throughout the day and year. The best approach is to collect as much data as possible and then track and trend the results, noting the current hydraulic conditions as best as possible. This approach should lead to a better understanding of the hydraulics of the distribution system and refinement of the sample timing at any given location.

Sampling Technique

Distribution system sampling is very inconsistent from system to system, and even within individual distribution systems. Sample tap flush times, monitoring techniques and monitored parameters are all highly variable and are typically targeted to the minimum compliance-related parameters (total chlorine, total coliform, DBPs).

As far as data integrity and sampling technique, sample tap flush time (prior to sampling) is one process that needs to be standardized to ensure data integrity. EPA has developed a method for sampling at both taps (inside taps, hose bibs, etc.) and hydrants that incorporates calculating a pre-sample flush time to ensure that water being sampled is from the main in the area of the sample location. This sampling technique allows for consistent sampling from sampling event to sampling event and ensures that neither over- nor under-flushing is occurring.

It is important to note that a sample collected after a calculated flush time (CFT), if done correctly, should represent the water from the main in the vicinity of the sample site. The monitoring results from that sample are representative of that water and should be recorded as such. The purpose of the sampling for distribution system optimization is to characterize the water quality, whether good or bad, within the distribution system at specific locations. Additional flushing should not occur to get a “good” sample, as this will not represent the water quality at that site. If additional flushing does occur, for example, to increase the chlorine residual reading at that site it will mask a potential problem in the system.

Tap Sampling

In general, the following steps should be taken to ensure that the water lines extending from the main to the sample tap has been properly flushed at the sample site:

1. Determine the *calculated flushing time* (CFT) based on an estimate of the pipe length, diameter, and flow rate.
2. Open the tap, start the timer and verify that the flow is at the desired rate (i.e., by quickly timing the fill of a liter bottle or by some other measurement). A flow-regulating device may also be used. For taps, flow rates should range between 1.2 and 2.8 gpm, but should be as close to 2 gpm as possible. If not using a flow-regulating device, the flow should be verified by timing the filling of a container of known volume (i.e., a 1-liter bottle fills in 8 seconds at 2 gpm).
3. Collect a water sample at ***twice*** the CFT.

A conservative CFT can be estimated using the matrix below (Figure 3), based on the estimated pipe length (to the nearest five feet) and inside diameter of the water line extending from the main to the sample tap. Collect a sample after the tap has been running for ***twice (2x) the CFT*** to allow for an adequate safety factor. If a water line at a sample site does not fall under the criteria listed on the table, then a CFT will have to be determined using a long-hand calculation.

Figure 3[1]

Number of Minutes needed to Flush Tap at 2 gpm											
Length	Inside (Nominal) Diameter of Pipe (inches)										
of Pipe	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
1	0.00	0.01	0.01	0.01	0.02	0.03	0.05	0.1	0.1	0.2	0.3
5	0.01	0.03	0.04	0.1	0.1	0.2	0.2	0.4	0.6	0.9	1.6
10	0.03	0.05	0.08	0.1	0.2	0.3	0.5	0.8	1.3	1.8	3.3
15	0.04	0.08	0.12	0.2	0.3	0.5	0.7	1.2	1.9	2.8	4.9
20	0.1	0.1	0.2	0.2	0.4	0.6	0.9	1.6	2.6	3.7	6.5
25	0.1	0.1	0.2	0.3	0.5	0.8	1.1	2.0	3.2	4.6	8.2
30	0.1	0.2	0.2	0.3	0.6	1.0	1.4	2.4	3.8	5.5	9.8
35	0.1	0.2	0.3	0.4	0.7	1.1	1.6	2.9	4.5	6.4	11.4
40	0.1	0.2	0.3	0.5	0.8	1.3	1.8	3.3	5.1	7.3	13.1
45	0.1	0.2	0.4	0.5	0.9	1.4	2.1	3.7	5.7	8.3	14.7
50	0.1	0.3	0.4	0.6	1.0	1.6	2.3	4.1	6.4	9.2	16.3
55	0.2	0.3	0.4	0.6	1.1	1.8	2.5	4.5	7.0	10.1	18.0
60	0.2	0.3	0.5	0.7	1.2	1.9	2.8	4.9	7.7	11.0	19.6
65	0.2	0.3	0.5	0.7	1.3	2.1	3.0	5.3	8.3	11.9	21.2
70	0.2	0.4	0.6	0.8	1.4	2.2	3.2	5.7	8.9	12.9	22.8
75	0.2	0.4	0.6	0.9	1.5	2.4	3.4	6.1	9.6	13.8	24.5
80	0.2	0.4	0.6	0.9	1.6	2.6	3.7	6.5	10.2	14.7	26.1
85	0.2	0.4	0.7	1.0	1.7	2.7	3.9	6.9	10.8	15.6	27.7
90	0.3	0.5	0.7	1.0	1.8	2.9	4.1	7.3	11.5	16.5	29.4
95	0.3	0.5	0.8	1.1	1.9	3.0	4.4	7.8	12.1	17.4	31.0
100	0.3	0.5	0.8	1.1	2.0	3.2	4.6	8.2	12.8	18.4	32.6
1. If service line diameter is 3" or greater consider selecting a different site as CFT could be long											
2. If plumbing is less than 3/8", assume this pipe volume is negligible											
3. Depending on the type of pipe material and degree of corrosion inside the pipe, the inner diameter will vary. These diameters are meant to be approximations.											

[1] This sampling procedure was developed by the U.S. Environmental Protection Agency (USEPA) Technical Support Center (TSC) and is based on a research study conducted at two systems in Kentucky. This guideline is intended for water systems where the customer owns the service line beyond the meter. However, if the responsibility of the water system includes the service line and premise plumbing (e.g., privately owned restaurant or government owned park) or if the sampler desires to collect a sample from the service line or tap to assess bacteriological quality or is sampling for other regulatory parameters with a regulation specified sampling technique, this guideline is not appropriate.

In situations that do not fall under the matrix provided, a long-hand calculation should be completed to determine the CFT using the pipe length, diameter and flow during pre-sample flushing. The equation is as follows.

Volume of pipe from tap to main =

$$\underset{\text{Pipe Length}}{\underline{\qquad\quad \text{ft}}} \times \left(\underset{\text{Pipe Diameter}}{\underline{\qquad\qquad \text{in}}} \right)^2 \times 0.0408 \frac{\text{gal x ft}^2}{\text{ft}^3 \text{ x in}^2} = \underset{\text{Volume}^1}{\underline{\qquad\qquad\qquad \text{gal}}}$$

CFT =

$$\frac{\underset{\text{Volume}^1}{\underline{\qquad\qquad\qquad \text{gal}}}}{\underset{\text{Estimated Flowrate}}{\underline{\qquad\qquad\qquad \text{gpm}}}} = \underset{\text{CFT}}{\underline{\qquad\qquad \text{min}}}$$

Unknown Configurations

In situations where the length or diameter of the water line from the main to the sample tap is unknown, assume a ***2-minute total flush time*** for this situation to allow for an adequate factor of safety. This assumption is based on the fact that many service lines typically have a diameter less than or equal to ¾" and have a length less than 100 feet. This typical line size (¾" or less) will flush (at a flow rate of ~2 gpm) in less than ~1 minute even if the pipe is 100 feet in length. This conservative flush time should account for variations in flow rate and inaccuracies in length estimates. If it is known that the sample tap distance is greater than 100 feet from the main or the diameter is greater than ¾", then efforts should be made to calculate a CFT. Note: For this rule of thumb to apply flow rates should be between 1.2 and 2.8 gpm, but should be as close to 2 gpm as possible.

Unknown Premise Plumbing

In cases where premise plumbing length is unknown and an alternative sample site cannot be located, temperature and CFT can be used *in combination* to indicate that adequate flushing time has been reached. In cases where the CFT estimate is not long enough the temperature *may* indicate that a longer flush time is needed. Temperature should stabilize to within 0.2 °C between readings (using a digital thermometer). Once this time has been established it can be documented and used for future sampling at the site.

Hydrant Sampling

In general, the following steps should be taken to ensure that the water lines extending from the main to the sample hydrant has properly flushed at the sample site:

1. Determine the CFT based on an estimate of the pipe length, diameter, and flow rate.
2. Open the hydrant, start the timer and verify that the flow is at the desired rate (i.e., by quickly timing the fill of a five-gallon bucket or by some other measurement). A flow-regulating device may also be used. For hydrants, flow rates should range between 10 and 30 gpm, but should be as close to 20 gpm as possible. If not using a flow-regulating device, the flow should be verified by timing the filling of a container of known volume (i.e., a five-gallon bucket fills in 15 seconds at 20 gpm).
3. Collect a water sample at ***twice*** the CFT.

A conservative CFT can be estimated using the matrix below (Figure 4), based on the estimated pipe length (to the nearest five feet) and diameter of the water line extending from the main to the hydrant. Collect a sample after the tap has been running for ***twice (2x) the CFT*** to allow for an adequate safety factor. If a water line at a sample site does not fall under the criteria listed on the table, then a CFT should be determined using a long-hand calculation.

Figure 4[2]

Number of Minutes needed to Flush Hydrant at 20 gpm						
Length of Pipe	Diameter of Pipe (inches)					
	2	4	6	8	12	16
5	0.0	0.2	0.4	0.7	1.5	2.6
10	0.1	0.3	0.7	1.3	2.9	5.2
15	0.1	0.5	1.1	2.0	4.4	7.8
20	0.2	0.7	1.5	2.6	5.9	10.4
25	0.2	0.8	1.8	3.3	7.3	13.1
30	0.2	1.0	2.2	3.9	8.8	15.7
35	0.3	1.1	2.6	4.6	10.3	18.3
40	0.3	1.3	2.9	5.2	11.8	20.9
45	0.4	1.5	3.3	5.9	13.2	23.5
50	0.4	1.6	3.7	6.5	14.7	26.1
55	0.4	1.8	4.0	7.2	16.2	28.7
60	0.5	2.0	4.4	7.8	17.6	31.3
65	0.5	2.1	4.8	8.5	19.1	33.9
70	0.6	2.3	5.1	9.1	20.6	36.6
75	0.6	2.4	5.5	9.8	22.0	39.2
80	0.7	2.6	5.9	10.4	23.5	41.8
85	0.7	2.8	6.2	11.1	25.0	44.4
90	0.7	2.9	6.6	11.8	26.4	47.0
95	0.8	3.1	7.0	12.4	27.9	49.6
100	0.8	3.3	7.3	13.1	29.4	52.2

[2] This sampling procedure was developed by the U.S. Environmental Protection Agency (USEPA) Technical Support Center (TSC) and is based on a research study conducted at two systems in Kentucky. This guideline is intended for water systems where the customer owns the service line beyond the meter. However, if the responsibility of the water system includes the service line and premise plumbing (e.g., privately owned restaurant or government owned park) or if the sampler desires to collect a sample from the service line or tap to assess bacteriological quality or is sampling for other regulatory parameters with a regulation specified sampling technique, this guideline is not appropriate.

In situations that do not fall under the matrix provided, a long-hand calculation will have to be completed to determine the CFT using the pipe length, diameter and flow during pre-sample flushing. The equation is as follows.

Volume of pipe from hydrant to main =

$$\underbrace{\underline{\qquad\qquad \text{ft}}}_{\textit{Pipe Length}} \;\text{X}\; \Big(\underbrace{\underline{\qquad\qquad \text{in}}}_{\textit{Pipe Diameter}}\Big)^2 \;\text{X}\; 0.0408\;\frac{\text{gal x ft}^2}{\text{ft}^3\text{ x in}^2} = \underbrace{\underline{\qquad\qquad\qquad \text{gal}}}_{\textit{Volume}^1}$$

CFT =

$$\frac{\underbrace{\underline{\qquad\qquad\qquad \text{gal}}}_{\textit{Volume}^1}}{\underbrace{\underline{\qquad\qquad\qquad \text{gpm}}}_{\textit{Estimated Flowrate}}} = \underbrace{\underline{\qquad\qquad \text{min}}}_{\textit{CFT}}$$

Unknown Configurations

In situations where the length or diameter of the water line from the main to the hydrant is unknown, assume a ***3-minute total flush time*** for this situation to allow for an adequate factor of safety. This assumption is based on the fact that the line from the main to the hydrant is six inches or less and has a length less than 20 feet. This line size (six inches or less) will flush (at a flow rate of ~20 gpm) in less than ~2 minutes even if the pipe is 20 feet in length. This conservative flush time should account for variations in flow rate and inaccuracies in length estimates. If it is known that the sample hydrant distance is greater than 20 feet from the main or the diameter is greater than six inches, then efforts should be made to calculate a CFT. Note: For this rule of thumb to apply flow rates should be between 10 and 30 gpm, but should be as close to 20 gpm as possible.

Caution should be exercised when sampling from a hydrant. This type of sampling can be hazardous and may damage the hydrant if done incorrectly. Most hydrants in Pennsylvania are of the dry barrel design, which require that the hydrant be operated fully open. A sampling device should be used that can be connected securely to the hydrant and that is capable of handling the flow and pressure of the hydrant being sampled. The sampling device should also be capable of regulating the flow so the CFT can be calculated correctly. Discharge from the sampler should be controlled as to not negatively impact the environment (e.g. a chlorinated water discharge to a receiving body of water), customers (e.g. ponded water in a yard) or create a hazardous situation (e.g. ice on a sidewalk or road).

Sampling Devices

Sampling devices can be used at both a tap and at a hydrant. These devices can be used to control the flow to the desired flow associated with the calculated flush time. These devices also enable a sample to be collected at a hydrant in a safer and more controlled manner.

Example sample device designs are included in Appendix A.

Recordkeeping

Once a CFT is calculated for a site, the CFT can be recorded and used for future sampling events (Figure 5). This ensures consistent sampling is occurring at that sample site, even when various operators are used to conduct the sampling.

Figure 5

SITE	CFT MIN	L
Entry Point	**NA**	
Hydrant A118	**2.5**	
Hydrant A156	**3**	
Hydrant A160	**4.75**	
Hydrant A162	**2**	
Hydrant B62	**2.25**	

As stated previously, when sampling using the CFT method, the monitoring results are representative of that water and should be recorded as such. The purpose of sampling for distribution system optimization is to characterize the water quality within the distribution system, whether “good” or “bad”. Additional flushing should not occur to get a “good” sample.

COLLECTING PROPER DATA

At most water systems in Pennsylvania comprehensive distribution water quality data is lacking. Distribution system water quality sampling is typically limited locationally, to regulatory sample locations (Total Coliform Rule (TCR) and Disinfection By-Product (DBP) Rule), and by parameter, also dictated by regulatory requirements. By limiting the sampling locations and parameters, a clear picture of water quality throughout the distribution system is typically not available.

Distribution systems are a complex network of pipes, tanks and pumps of various sizes, ages and materials. There are no two systems that are alike, in either construction or operation, which provides a challenge when starting optimization efforts. It is therefore imperative for systems to have a full understanding of the physical aspects of their own system and how these aspects, as well as operation, can impact water quality.

In order to gain a more comprehensive characterization of water quality within the distribution system, additional sampling beyond regulatory sampling frequencies, locations and parameters should be conducted. This can be done, using a process called "Chlorine Mapping."

Chlorine Mapping is a process that a water system can use to identify the most critical, as well as representative, sample locations (for chlorine residual, DBPs, or other target parameters) throughout the distribution system. Chlorine Mapping can be used to establish a long-term monitoring program which can be used as a process control tool and as an "early warning system" for locational and system-wide distribution system water quality problems.

Free chlorine is used in the mapping process since it can be an indicator of higher water age, higher THMs, poor microbial water quality (biogrowth) and contamination. Also, in areas where there is low to no chlorine, the chemical barrier is no longer present or effective in the event of an intentional or unintentional contamination event. Identifying these areas is critical in ensuring effective public health protection.

Using the guidelines presented, a system can identify potential "critical" areas within the distribution system to monitor. Initially, a large number of investigative sample locations may be selected to ensure comprehensive coverage of the entire distribution system. Once an initial sampling event is conducted, the number of "critical" sample locations may be narrowed down to sites that will accurately characterize the water quality within the distribution system and can be used for long-term sampling. It is also important to ensure that the number of long-term sample sites is not excessive, requiring too much time and causing workforce issues or "hit-or-miss" sampling.

Getting Started – Investigative Sampling

There are several tools that are needed to identify the investigative distribution sample locations, including:

- An accurate distribution system map
- Historical water quality data
- Historical complaint records
- System personnel with intimate knowledge of distribution system layout, construction, hydraulics and water quality.

By using these tools and the following guidelines, an initial comprehensive set of sampling locations can be identified.

Site Identification Guidelines

When selecting sample locations it is important to select locations that are going to be easily accessible (e.g. fire hydrants) and will be suitable for the parameters being measured. For example, if biological analyses are being incorporated into the sampling, fire hydrants may not be the best sampling locations. The sample locations should be accessible on a routine basis, if there is potential for these locations to be chosen as long-term sample sites.

Where to look [3]:

Tanks:

- Downstream of storage tanks (representative of water exiting the tank)
- Upstream of tanks (representative of water entering the tank)
- Inside the tank, if sample taps are able to capture water quality inside the tank at different depths

Hydraulic problem areas:

- In pressure zones near the ends of the distribution system
- On dead-ends [4]
- On looped dead-ends (subdivisions)
- Towards the "extremities" of the distribution system (hydraulically far from the treatment plant)
- Near pressure zone boundaries that result in isolated use areas (i.e., where a valve is closed creating a "hydraulic" dead-end)
- Areas where water from different sources is blended

Areas with aging pipes:

- On old cast iron lines

Low demand, low flow, stagnant areas:

- In low demand, stagnant, high water age areas of the system with customer impact
- In areas with oversized mains (versus demand)

Water quality problem areas:

- At TCR/ DBP sites with historically low chlorine residual, high DBPs, coliform occurrences or high heterotrophic plate counts (HPCs)
- Areas with persistent customer complaints or known water quality issues

[3] It is important to note that areas where there is no customer consumption or impact on water quality in other areas being consumed may not be the best areas to target. These areas may be acceptable to get a general understanding of water quality, but are not areas that should be used when gauging distribution optimization efforts since there is no impact on public health or protection.

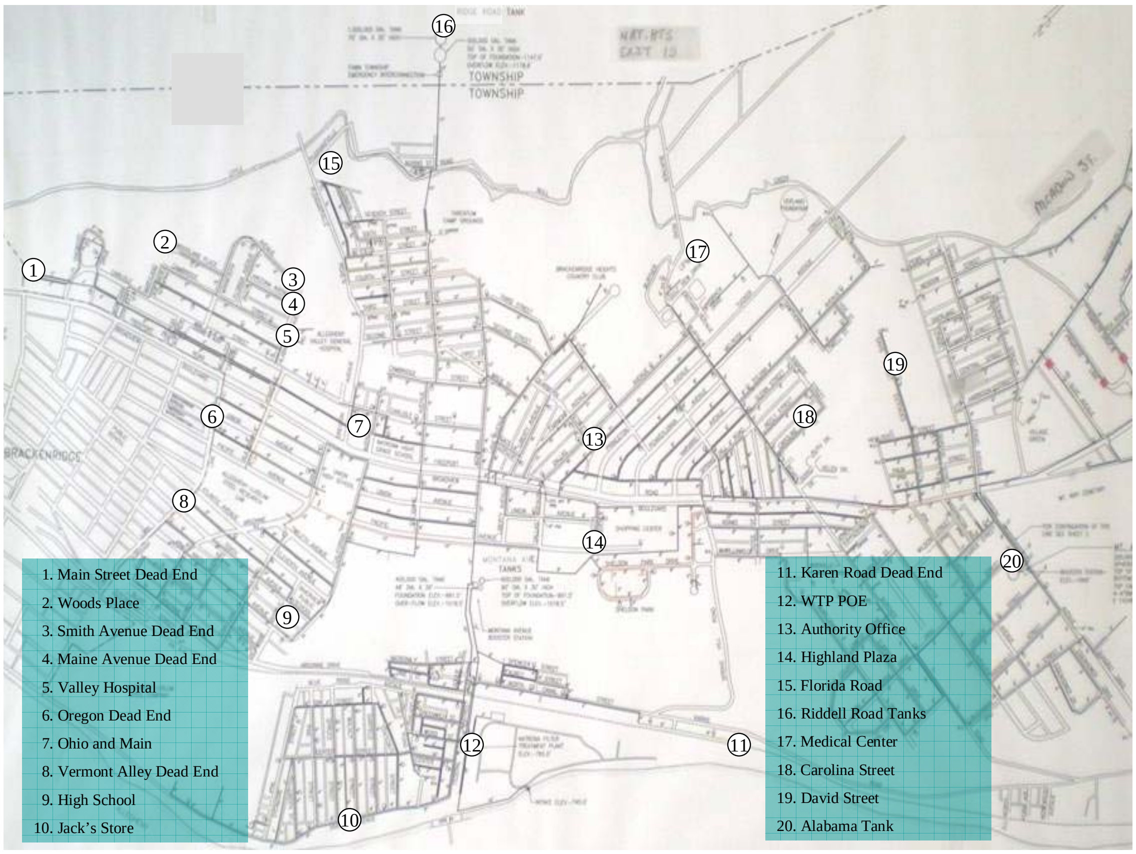
[4] Sampling at dead-ends is a critical part of distribution system optimization, but it should be part of an overall evaluation that includes other sites that are not dead-ends. Typically, dead-end sampling should be done sparingly unless dead-ends are common in the system.

Essential Sample Sites:

- Plant finished water/ entry point (EP) (to be used as a baseline)
- Near the entry to pressure zone(s)/consecutive system or midpoint of the system (in order to assess the level of chlorine loss throughout the distribution system or to track and understand the system hydraulics)
- Tank(s)
- Maximum residence time site (represents worst case scenario)

Once sample locations have been identified using the tools and guidelines provided, a copy of the distribution map can be used to mark the sample site locations. This should be done in order to ensure comprehensive coverage of the distribution system. An example distribution system map with initial sample locations is shown in Figure 6.

Figure 6



Sampling Guidelines

Once sample locations have been selected, focus will turn to:

- Sample timing
- Parameters

Sample timing should follow the procedure described in the *Data Integrity* section of this document. In addition, the following specific activities should also be considered when determining the timing of distribution system sampling:

- At tanks, *when the tank is both filling and draining.*
- At the water treatment plant entry point, distribution system entry point (if consecutive) or other sites with variable residual (e.g. booster chlorination) when water is flowing.

- Prior to and during high use in a specific area of the distribution system (e.g. a high use industry that operates 8 a.m. to 8 p.m.).

Parameters

When characterizing a system using free chlorine as the primary oxidant, there are several field tests that can be conducted at each sample location that can be used as indicators of changing or degraded water quality. They include:

- Free Chlorine
  - Low to no free chlorine significantly compromises the protective barrier
  - Low to no free chlorine may be associated with a reaction to a contaminant in the water
  - Low to no free chlorine may indicate elevated biogrowth in that area of the distribution system
  - Low to no free chlorine may be associated with a reaction with unlined or tuburculated piping
  - Low to no free chlorine may indicate hydraulic conditions within the distribution system causing high water age
  - If related to water age, low free chlorine may be associated with elevated TTHMs
- Temperature
  - Significant increases in water temperature can indicate insufficient tank turnover and mixing, leading to stratification of the water within the storage tank
  - Significant increases may indicate backflow into the system from an industrial user or from a household with an improperly installed hot water heating system
- Total Chlorine
  - Low to no total chlorine may indicate the same conditions associated with free chlorine
  - Significant (>0.20 mg/L) differences between free and total chlorine at any given site may indicate a potential backflow or introduction of ammonia-based contaminant
  - Significant (>0.20 mg/L) differences between free and total chlorine system wide may indicate ammonia within the source water(s) that is reacting with the free chlorine to form a combined residual
- pH
  - Significant variations in pH may indicate a potential backflow or introduction of contaminant
  - TTHM formation typically increases as pH increases

Field-ready equipment and reagents are available for each of these parameters. As with any sample analysis, it is important to follow the manufacturer's analysis and quality control procedures or EPA-approved methods. Not following the proper procedures may lead to inaccurate and inconsistent data, which could hinder data trending and analysis.

Additional analysis may be conducted that may be used to characterize the distribution system water quality. This can vary from system to system and may be related to sampling currently being conducted at the site or system specific issues (e.g. elevated DBPs). Additional parameters may also assist in interpreting the other data being collected. Additional analysis may include, but is not limited to:

- Heterotrophic Plate Counts
- Total Coliform
- TTHMs
- HAAs
- HACH THM Plus (TTHM surrogate)
- Turbidity

- Conductivity
- Oxidation-Reduction Potential

It is important to keep in mind that the first round of investigative sampling is primarily for identifying future long-term monitoring locations. It will typically encompass a large number of sample locations. Adding additional parameters, beyond the primary field tests listed, may create an overwhelming and time consuming task with little benefit. Additional parameters may be best suited for the long-term monitoring.

Recordkeeping

While sampling is being conducted, it is important to accurately log the data being collected for future analysis and identification of long-term sample locations. A log should be maintained for each sample site. Consider using the following the format and including the basic information shown in Figure 7.

Figure 7

DISTRIBUTION OPTIMIZATION SAMPLE LOG
Investigative Sampling
May-10

SITE	CFT MIN	Date	Time	TEMP F	pH	FREE CL mg/L	TOTAL CL mg/L	Sampler	COMMENTS
Entry Point	NA	5/11/2010	8:00	50.2	7.48	1.25	1.28	PX	Plant start-up was at 7:00
Hydrant A118	2.5	5/11/2010	8:15	55.1	7.60	0.04	0.08	PX	
Hydrant A156	3	5/11/2010	8:45	54.0	7.48	0.35	0.35	PX	
Hydrant A160	4.75	5/11/2010	9:05	53.0	7.25	0.21	0.24	PX	
Hydrant A162	2	5/11/2010	9:13	58.2	7.80	0.18	0.21	PX	
Hydrant B62	2.25	5/11/2010	9:32	56.0	7.60	0.65	0.66	PX	
Hydrant B130	3	5/11/2010	9:52	55.2	7.23	0.13	0.19	PX	
Hydrant B145	4.5	5/11/2010	10:09	53.1	7.15	0.02	0.08	PX	
Hydrant B152	3	5/11/2010	10:25	50.1	7.25	0.43	0.50	PX	
Hydrant C12	2.5	5/11/2010	10:42	56.4	7.15	0.65	0.65	PX	
Hydrant C89	1.75	5/11/2010	10:57	57.3	7.46	0.81	0.93	PX	
North Tank - filling	0.5	5/11/2010	11:15	50.3	7.41	0.72	0.75	PX	Tank filling for 4.25 hours prior to sample
North Tank - drawing	0.5	5/11/2010	15:25	58.3	7.69	0.03	0.10	PX	Tank drawing for 0.5 hours prior to samp'
South Tank - filling	0.5	5/11/2010	11:32	51.3	7.43	0.95	0.98	PX	Tank filling for 4.5 hours prior to sample
South Tank - drawing	0.5	5/11/2010	15:50	57.9	7.67	0.05	0.16	PX	Tank drawing for 1 hour prior to sample

Long-Term Monitoring

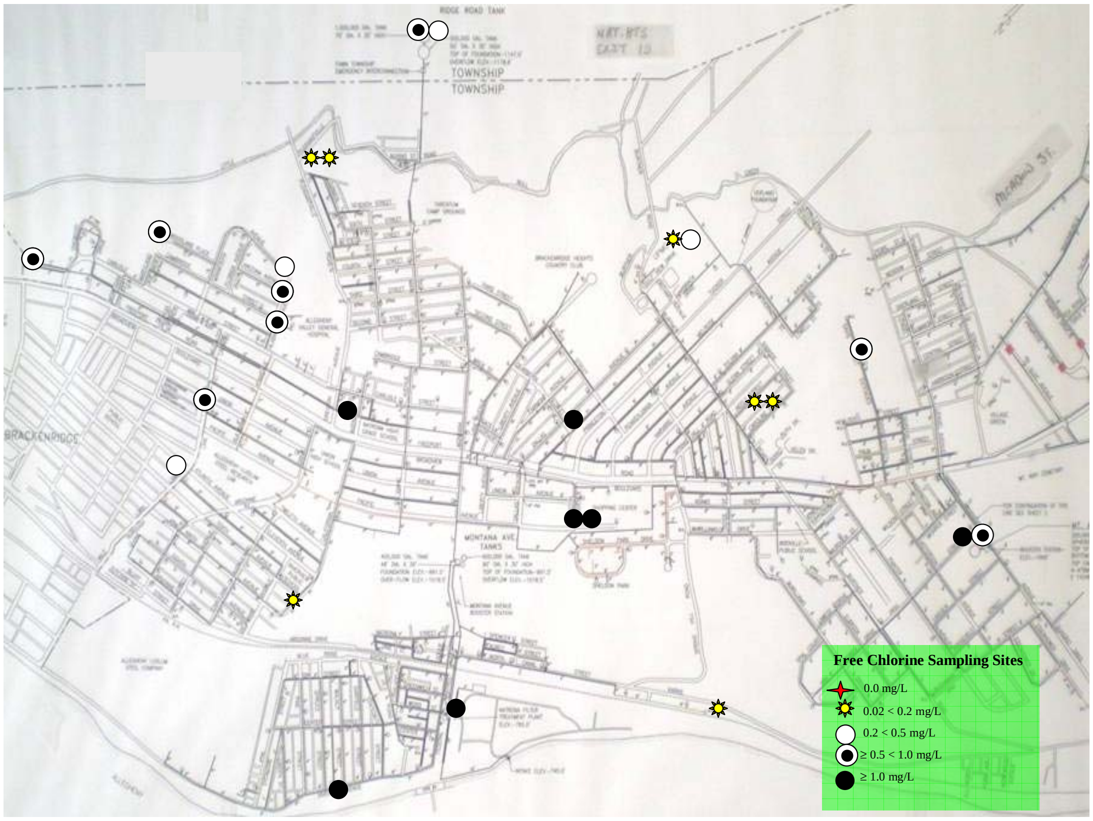
Once the investigative sampling is completed, the process of "Chlorine Mapping" can be used to select long-term monitoring locations. During the "Chlorine Mapping" process, free chlorine is used as the primary surrogate to gauge water quality in the distribution system. It is important though to not rely solely on the free chlorine data. If one or more of the other parameters monitored indicate potential water quality issues at a specific sample location (e.g. high pH), then that site may be included in the long-term monitoring plan.

Long-Term Monitoring Site Selection

Figure 7 shows an example of data gathered during the investigative sampling stage of the chlorine mapping process. As seen in Figure 8, the free chlorine results for each sample location are categorized based on the concentration:

- 0.00 mg/L
- 0.02 to 0.20 mg/L
- 0.20 to 1.00 mg/L
- > 1.0 mg/L

Figure 8



Once the mapping is completed, the process of long-term monitoring site selection is conducted in conjunction with the use of the raw data collected during the investigative sampling.

Critical Location Identification

Although compliance monitoring locations may be good to use as a base for establishing the long-term monitoring plan, mainly because they must be sampled routinely for compliance purposes anyway, it is important to select other non-compliance locations to ensure that data is collected in other areas of the distribution system that are not required to be monitored by regulation.

The first set of “critical” locations would correspond to those locations with degraded free chlorine, relative to all the samples taken. Due to seasonal and temporal variations, the results should be compared and the most compromised locations identified. During the investigative sampling, there may not be sites with low (0.20 mg/L of less) to no free chlorine, but there are most likely sites that have degradation relative to the entire distribution system. Once long-term monitoring is conducted, a clearer picture of seasonal and temporal degradation may become apparent.

Once the “critical” locations are identified, other sites may be included based on the other water quality data collected (e.g. high pH), including sites with “good” or non-degraded water quality that can be used as a baseline.

In addition, and as stated during the investigative site *Sampling Guidelines*, several key locations should always be included in the long-term monitoring plan, including:

- At tanks, *when the tank is both filling and draining.*
- At the water treatment plant entry point, distribution system entry point (if consecutive) or other sites with variable residual (e.g. booster chlorination) when water is flowing.

The number of long-term monitoring locations will vary from system to system based on system size and “critical” site identification. As stated previously, it is important to ensure that the number of long-term sample sites is not too excessive, requiring too much time and causing workforce issues or "hit-or-miss" sampling.

It is also important to note that sample locations may have to be added or removed from the long-term sampling plan based on additional data that is collected (e.g. water quality data collected during a complaint) or conditions that prevent access to a particular sample location (e.g. business closes).

Conducting the Sampling

Once the locations are selected, long term monitoring can begin. It is important to continue to ensure data integrity following the guidelines outlined in the *Ensuring Data Integrity* section of this document. The sample collection procedures and timing criteria established at the beginning of the long-term monitoring should be continuously followed. If sampling procedures or timing is changed then the integrity, trendability and comparability of the data may be compromised.

There are no specific recommendations for frequency of sampling. The more data that can be collected at a site, the better the data trending and analysis will be. At a *minimum* it is recommended that sampling be conducted at least monthly at all long-term monitoring locations.

Recordkeeping

When conducting long-term monitoring, it is important to accurately record and track the data being collected. Recordkeeping is one key to continuing distribution optimization efforts, as well as making and tracking process control decisions. Without accurate data, proper decisions cannot be made and the resultant water quality changes cannot be tracked. It is possible that process control decisions may have an adverse impact on water quality. Without the proper background data, the changes, whether good or bad, cannot be accurately demonstrated.

The data should be recorded locationally, as seen in Figure 9, and system-wide, as seen in Figure 10.

Figure 9

Site 1 ID	Hydrant A118							
Date	TTHM ppb	HAA5 ppb	THM Plus ppb	Temp. F	FreeCl2 ppm	TotalCl2 ppm	pH units	THM [illegible]
11/24/08	36	23	30.0	53.6	0.56	0.69	7.48	0.8
1/13/09	26	28	18.0	43.6	0.69	0.76	7.7	[illegible]
2/17/09	20	36	12.0	41.2	0.8	0.93	7.65	[illegible]
3/17/09	29	36	20.0	43.6	0.87	1	7.56	[illegible]
4/23/09	39	33	31.0	50.8	0.81	0.93	7.72	[illegible]
5/19/09	45	29	40.0	56.9	0.6	0.69	7.75	[illegible]
6/22/09	49	26	38.0	65.0	0.14	0.24	7.65	[illegible]
Average	34.9	30.1	27.0	50.7	0.6	0.7	7.6	[illegible]
Min	20.0	23.0	12.0	41.2	0.1	0.2	7.5	[illegible]
Max	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Locational data can be used to track water quality in that spot over time and will be useful in determining trends and anomalies that may be occurring at that site.

Figure 10

DISTRIBUTION OPTIMIZATION SAMPLE LOG

Jul-10

SITE	CFT MIN	Date	Time	TEMP F	pH	FREE CL mg/L	TOTAL CL mg/L	HPC CFU/mL	TTHMs ppb	HAAs ppb	THM PLUS ppb CHCl3	Sampler	CO
Entry Point	NA	7/12/2010	8:05	58.2	7.48	1.00	1.03	0	38	36	28	PX	Plant start-up wa
Hydrant A118	2.5	7/12/2010	8:20	62.1	7.60	0.02	0.08	32	92	12	70	PX	
Hydrant A156	3	7/12/2010	8:50	63.0	7.48	0.32	0.35	10	75	23	68	PX	
Hydrant A160	4.75	7/12/2010	9:10	59.0	7.25	0.20	0.24	8	65	20	55	PX	
Hydrant A162	2	7/12/2010	9:20	63.5	7.80	0.16	0.18	16	70	19	60	PX	
Hydrant B62	2.25	7/12/2010	9:40	59.0	7.60	0.42	0.50	6	42	30	35	PX	
Hydrant B130	3	7/12/2010	9:58	59.8	7.23	0.10	0.15	21	68	22	60	PX	
Hydrant B145	4.5	7/12/2010	10:14	58.9	7.15	0.02	0.08	56	90	13	71	PX	
Hydrant B152	3	7/12/2010	10:32	55.5	7.25	0.32	0.40	6	60	26	48	PX	
Hydrant C12	2.5	7/12/2010	10:50	60.3	7.15	0.70	0.72	0	45	33	35	PX	
Hydrant C89	1.75	7/12/2010	11:03	63.7	7.46	0.62	0.65	3	65	31	56	PX	
North Tank - filling	0.5	7/12/2010	11:21	55.1	7.41	0.90	0.98	0	53	34	40	PX	Tank filling for
North Tank - drawing	0.5	7/12/2010	15:29	64.9	7.60	0.02	0.10	0	89	26	61	PX	[illegible]

System-wide data will be useful in seeing water quality over the entire system.

The locational and system-wide hard data, demonstrated in Figures 9 and 10, can be used to graphically create trends which should enhance data analysis and decision-making processes.

TRENDING THE DATA

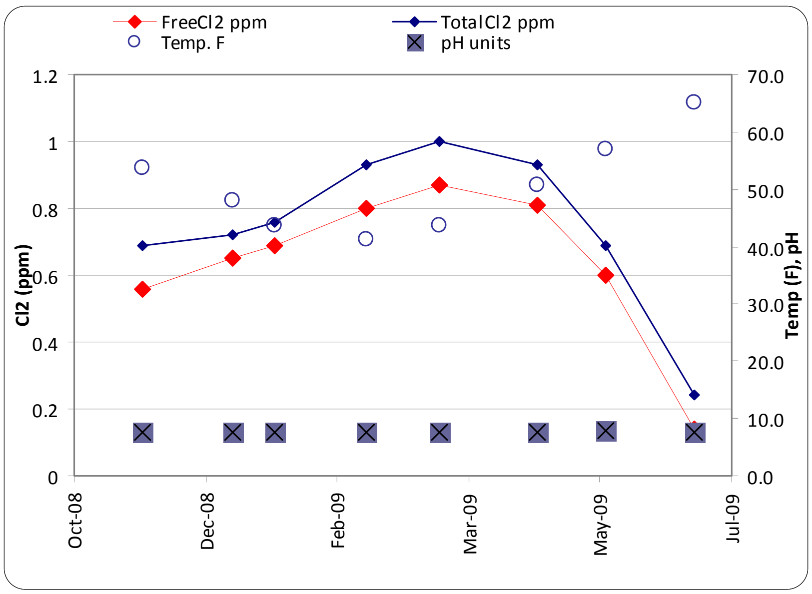
Once the long-term data collection has started, it is important to implement a trending program to show how water quality changes over time. Data trending is a useful tool to graphically represent changes over time, which may not be noticed when looking at individual data sets (e.g. table of data).

Many computer software packages exist to assist with data management and trending. Computer software can be used to trend both the locational and system-wide data that is collected during the long-term sampling. EPA's Distribution Water Quality Assessment Software can be obtained by contacting DEP.

Locational Data

Looking at locational trends will provide insight into water quality changes locationally on a temporal or seasonal basis. For example, at the location demonstrated in Figure 11, both free and total chlorine decrease significantly as the water temperature increases during the summer months.

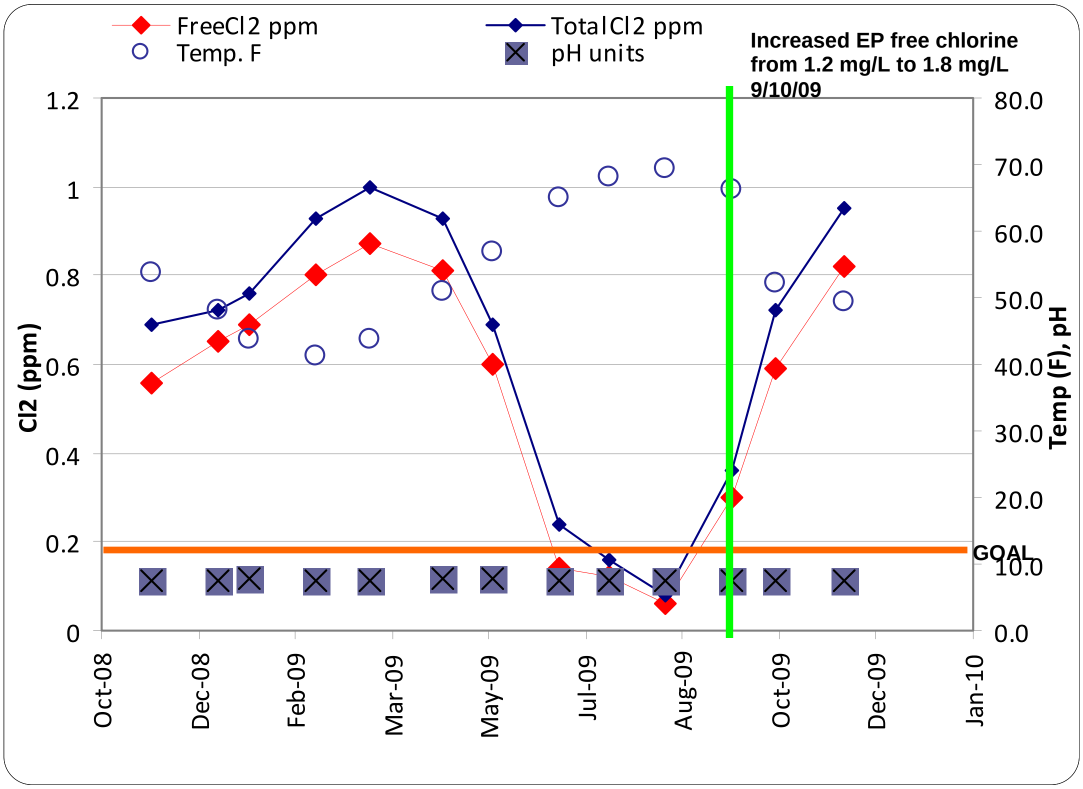
Figure 11



Trending is also used to track the impact of operational changes that are instituted to improve water quality in the area of that sample location. This type of data analysis will also help to ensure that established operational and optimization goals are being met.

For example, in Figure 12, an optimization goal, to maintain a free chlorine residual of 0.20 mg/L at all sample locations, was established by the system. In order to meet the optimization goal, the free chlorine residual at the entry point (EP) was raised from 1.2 mg/L to 1.8 mg/L. By trending the data, the increase in free chlorine residual at this location, above the system goal, is demonstrated. Continual monitoring and trending will further demonstrate if improvement is achieved year-round, especially during the months when the free chlorine residual was below the system optimization goal.

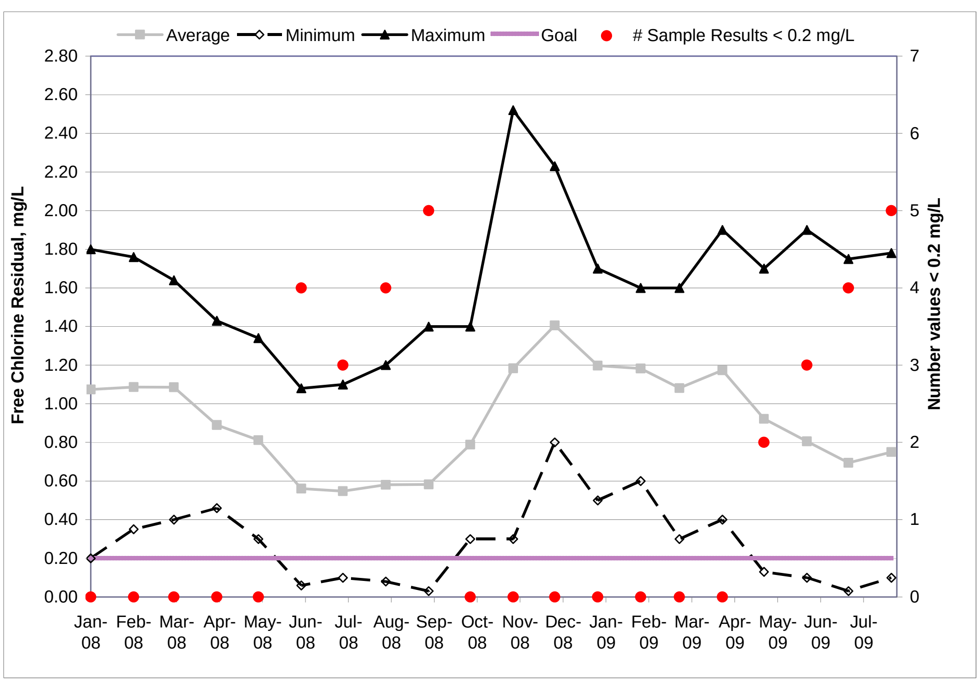
Figure 12



System-Wide Data

System-wide data trending is useful in determining if trends are occurring system-wide or if locational trends or issues are limited to that location. The trending can be done various ways. An example of a system-wide data trend is shown in Figure 13.

Figure 13

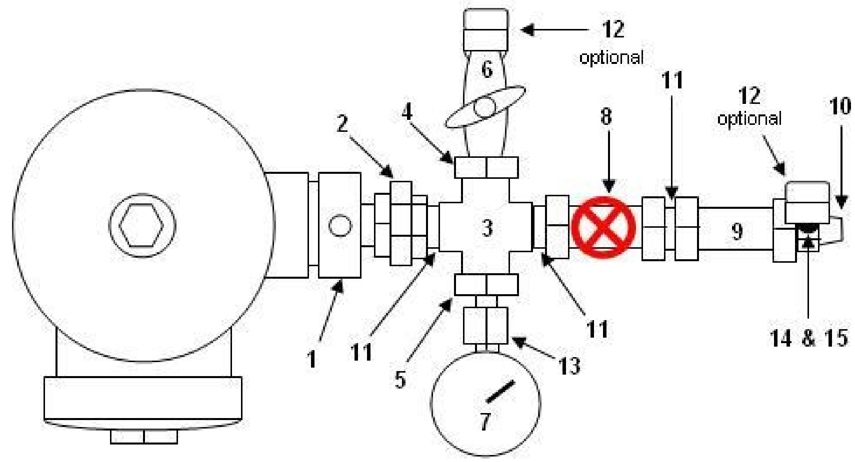


In this example, system-wide free chlorine residuals are trended based on maximum and minimum individual samples for the month and monthly average. This graph also provides the number of samples taken during each month that did not meet the system's free chlorine optimization goal of 0.20 mg/L. This graph demonstrates that there is system-wide free chlorine degradation during the warmer summer months (June – Sept.). When compared to individual site trends, this may provide some guidance as to whether water quality issues need to be addressed system-wide or in specific locations or portions of the system.

For more information about the concepts presented in this document or assistance in developing your own distribution optimization program, please contact the Pennsylvania DEP at (717)772-4018.

APPENDIX A

Hydrant Sampler with Pressure Gauge & 20 GPM Flow Control



ID	Description
1	Brass Hydrant Reducer – 2-1/2" female NPT x 1" Male[1]
2	Brass Union - 1"
3	Cross Brass – 1”
4	Hex Bushing - 1 x 1/2”
5	Hex Bushing – 1 x 1/4”
6	Hose Bibb, ½ In MNPT, Celcon, 150 PSI
7	WIKA 300 PSI Pressure Gauge
8	Bronze Gate Valve - 1"
9	#20 GX - 20 GPM Dole Flow Control
10	Adapter Male 1" (Tube to Barb)
11	Brass Pipe Nipple - 1"
12	Cooper Waterproof Digital Thermometer
13	Gauge Filter Snubber
14	Pipe Hex Bushing 1/4 MIP x 1/8” FIP * Requires Tube to Barb adapter (Part # 5YM53) to be drilled and tapped
15	Quick Connect Male Adapter 1/4 OD (1/8” CTS) X 1/8” MIP * Requires thermometer stem to be covered with 1/4 OD tubing

[1] *Various threads are present on hydrants throughout Pennsylvania. A thread adapter or reducer with the appropriate threads must be used for proper and safe installation of the sampler to the hydrant.*

Hydrant Sampler Instructions

In distribution system sampling, oftentimes residential or business taps are not available for sampling at critical locations, so hydrants must be used. Since hydrants are designed to be fully open, a device is needed to keep the hydrant fully open, but allow the sampler to sample the water in a controlled and safe manner.

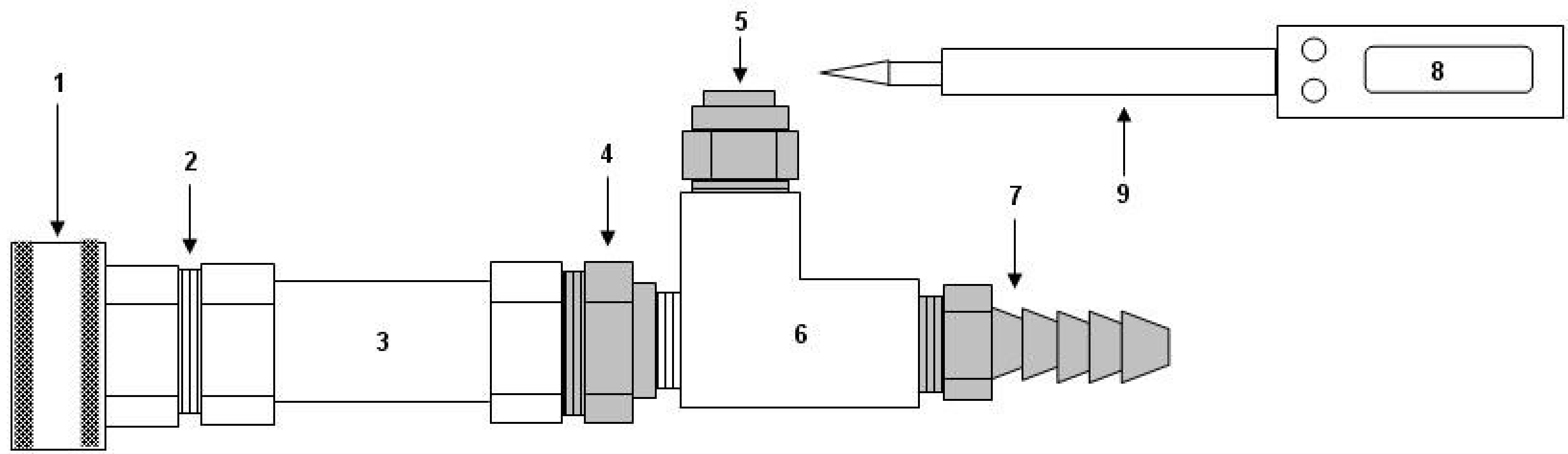
The following is the protocol when using the hydrant sampler described on the backside of this sheet:

- Close all valves on the sampler and connect to the hydrant.
- Open the hydrant fully.
- If checking the pressure at the hydrant:
  - Slightly open the main gate valve on the sampler to allow the brass cross to be filled with water and then close the valve.
  - Record the static pressure.
- Open the main gate valve fully[1]. Once open start the timer for the calculated flush time (CFT).
- Monitor and record the temperature of the water being flushed.
- While flushing, open the sample tap temporarily to flush the tap.
- Once the hydrant has been flushed for twice (2x) the CFT, close the main gate valve, open the sample tap and take the sample(s).
- Record the water temperature at the time of the sample or at the end of the flush (depending on the location of the thermometer).
- When sampling is completed, shut off all the valves and close the hydrant completely.
- Open the main gate valve slightly to release any residual pressure and to ensure that the hydrant has closed completely.
- Remove the sampler and re-cap the hydrant.

Caution: Sampling from a hydrant can be hazardous and may damage the hydrant if done incorrectly. Most hydrants in Pennsylvania are of the dry barrel design, which require that the hydrant be operated fully open. A sampling device should be used that can be connected securely to the hydrant and that is capable of handling the flow and pressure of the hydrant being sampled. The sampling device should also be capable of regulating the flow so the CFT can be calculated correctly. Discharge from the sampler should be controlled as to not negatively impact the environment (e.g. a chlorinated water discharge to a receiving body of water), customers (e.g. ponded water in a yard) or create a hazardous situation (e.g. ice on a sidewalk or road).

[1] If the hydrant sampler is constructed without the 20 gpm flow regulator, then the main gate valve will have to only be opened to allow for an estimated 20 gpm flow rate.

Tap Sampler with Temperature Probe & 2 GPM Flow Control



ID	Description	Quantity
1	Water Hose Coupling 1/2" X 3/4" NH(F)	1
2	1/2" Close Nipple	1
3	#2 GB – 2 GPM Dole Flow Control	1
4	Reducing Bushing – 1/2" x 1/4" Black Polypropylene	1
5	Quick Connect Male Adapter 1/4 OD (1/8" CTS) X 1/8" MIP * Requires thermometer stem to be covered with 1/4" OD tubing	1
6	Street Run Tee 1/4" Brass	1
7	1/2" Nipple X 1/4" NPT	1
8	Cooper Waterproof Digital Thermometer	1
9	1/4" OD Rubber Tubing	1

For more information, visit www.depweb.state.pa.us,
keyword: Filtration.

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