Area-Wide Optimization Program's (AWOP) Approach to Maintaining Distribution System Water Quality

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Presentation Outline

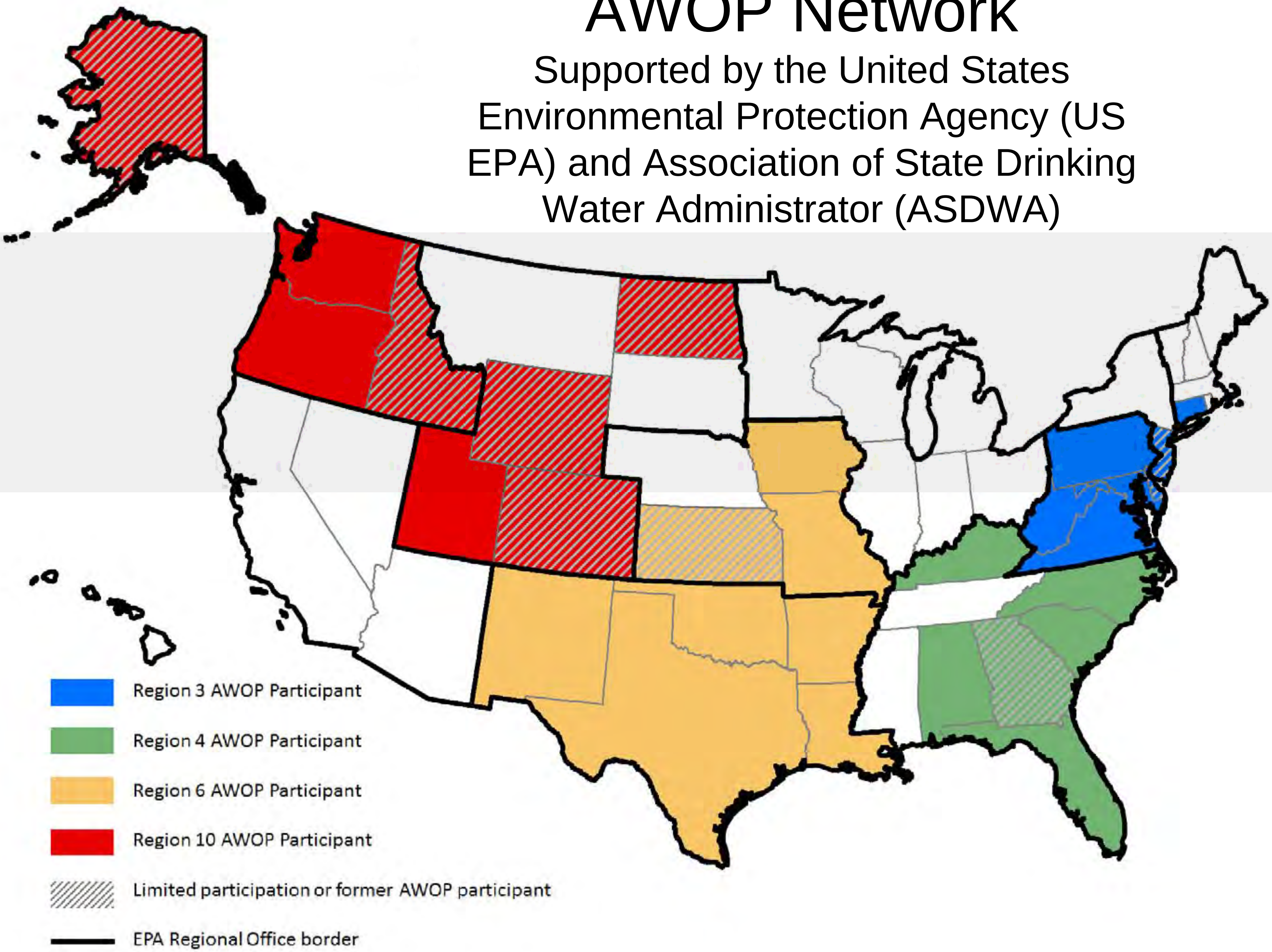
- Area-Wide Optimization Program (AWOP) Background
- Water Quality Performance and Monitoring Goals/ Guidelines
- Water Treatment and Distribution System (DS) Considerations
  - Tools and approaches to characterize water quality leaving the plant and into the distribution system
  - Strategies to improve/maintain water quality in the distribution system
- Summary

Area Wide Optimization Program (AWOP)

- Optimization program encourages drinking water quality beyond compliance levels, to increase public health protection through:
  - Enhanced process monitoring and control
  - Using existing staff and facilities
  - Measuring performance relative to optimization goals
  - Technical tools and implementation approaches focus on improving and/or maintaining water quality – using the multiple barrier approach
- The program began in 1989 with microbial (turbidity) optimization at surface water treatment plants and has expanded to other areas – including the distribution system for free chlorine and chloramine systems

AWOP Network

Supported by the United States Environmental Protection Agency (US EPA) and Association of State Drinking Water Administrator (ASDWA)



Distribution System Optimization Focus:
DBPs & Disinfectant Residual

- Disinfection byproducts (DBPs) form when chlorine (or other disinfectants) reacts with organic matter (total organic carbon (TOC))
  - Formation starts in the water plant and continues into the distribution system
  - Water age and temperature impact formation

Chlorine Dose + **Organic Matter (TOC)** → **Chlorine Residual** + **DBPs**

- Disinfectant residual decreases (decays) in the distribution system due to water age (reaction time), bulk water reactions pipe-wall reactions (e.g., pipe material, biofilm), etc.

AWOP Goals and Guidelines

- Goals have been established for treatment and distribution system
- All goals focus on water quality (opposed to best management practices)
  - Performance goals provide targets for operators
  - Monitoring goals support assessment of system performance relative to performance goals
- Performance goals and guidelines are more stringent than regulatory requirements; research indicates these water quality goals increase public health protection

Treatment Goals/Guidelines

- Total Organic Carbon (TOC) Removal Goal
  - Based on source water TOC and alkalinity concentration
  - 10% factor of safety over regulatory requirement
  - Based on monthly monitoring (or more frequently when challenged)
- Plant Effluent DBP Goal – system specific!
  - Recommend goal value/range to be 30% to 50% of the (long-term) distribution system goals
  - TTHM: ~20 to 30 ppb
  - HAA5: ~15 to 20 ppb
  - Recommend quarterly monitoring, or more frequently if challenged

Treatment Goals/Guidelines

- Ammonia Control Guideline (Chloramine Systems)
  - Performance Goal
    - Minimize free ammonia to ≤ 0.10 mg/L (as N) in the plant effluent
  - Monitoring Goal
    - Monitor free ammonia at least once per day in the plant effluent
      - The monitoring frequency may be adjusted based on the variability observed over an extended period of time
      - Free ammonia may be monitored in the source water periodically (e.g., once per week) to assess variability

Free Chlorine DS Goals

- Performance Goal
  - Maintain ≥ 0.20 mg/L free chlorine at all locations in the distribution system at all times
- Monitoring Goal
  - Monitor monthly (and more frequently at critical times) at the following locations:
    - o Established TCR and DBP compliance sites
    - o System entry point and consecutive system master meters
    - o All storage tanks (while draining)
    - o Critical sites (four minimum)

Chloramine DS Goals

- Performance Goal
  - Maintain > 1.50 mg/L monochloramine <u>at all locations in the distribution system at all times</u>, to provide a disinfection barrier against both *microbial contamination* and *nitrification prevention*
- Monitoring Goals
  - Monitor monthly (and more frequently at critical times) at same locations as free chlorine monitoring goal
  - Collect monochloramine and free ammonia samples at all monitoring sites, including the plant effluent (or system entry point(s))
  - Collect nitrite (and nitrate if desired), at the plant effluent (or system entry point(s)) and at distribution system sample locations where monochloramine residual is ≤ 1.50 mg/L, as a surrogate parameter for nitrification

DBP DS Goals

- Performance Goals
  - Individual Site Goal: Quarterly maximum locational running annual average (LRAA) TTHM/HAA5 values not to exceed 70/50 ppb
  - Long-Term System Goal: Average of Maximum LRAA TTHM/HAA5 values not to exceed 60/40 ppb (based on 11 quarters of data)
- Monitoring Goals
  - Systems meeting the goals: quarterly at plant effluent and DBP compliance sites
  - System not meeting the goals: monthly at system entry point, DBP sites, master meters, and minimum of four critical sites

Operational Guidelines for Storage Tanks

- Operational Guidelines
  - Maintain low turnover time[1] (less than five days) at all times, or establish/maintain a tank-specific water turnover rate
  - Maintain good mixing[2] (PR $\geq$1) at all times at each individual storage tank

[1] Average time that water is in a tank

[2] Mixing performance ratio (PR): a measurement of actual mixing/ desired mixing

Water Quality

Optimization Tools & Approaches to Evaluate and Improve Water Quality

Treatment & Distribution System Considerations

- Optimization tools can identify the source of water quality issues: water treatment, distribution system operations, or both!
- Once this is understood, efforts can be directed to improve water quality:
  - In-plant optimization approaches focus on TOC removal and optimizing disinfection – to minimize in-plant DBP formation and/or maximize disinfectant stability
  - Distribution system optimization approaches focus on minimizing water quality degradation in the distribution system

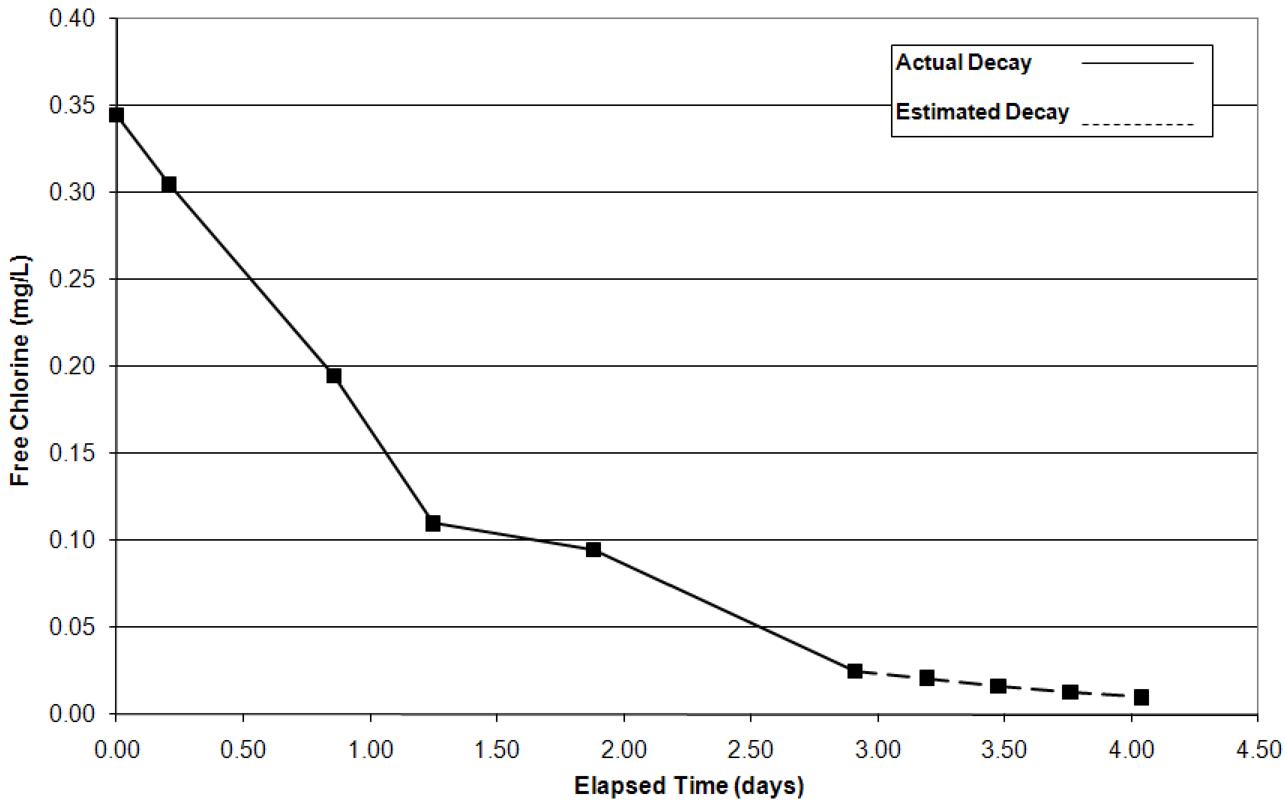
Treatment & Distribution System Considerations

- Evaluation tools include:
  - **Distribution System Influent Hold Study**: assess stability of water quality entering the system (i.e., from the plant effluent or master meter)
  - **Chlorine/Ammonia Dosing Evaluation**
  - **Optimization monitoring** in the distribution system
- Corrective strategies to minimize water age and improve water quality include:
  - **Tank Operations**
  - **Strategic Flushing**
  - **Rerouting Water**
- Parameters differ for free chlorine and chloramine systems, but the overall approach is very similar!

Distribution System Influent Hold Study

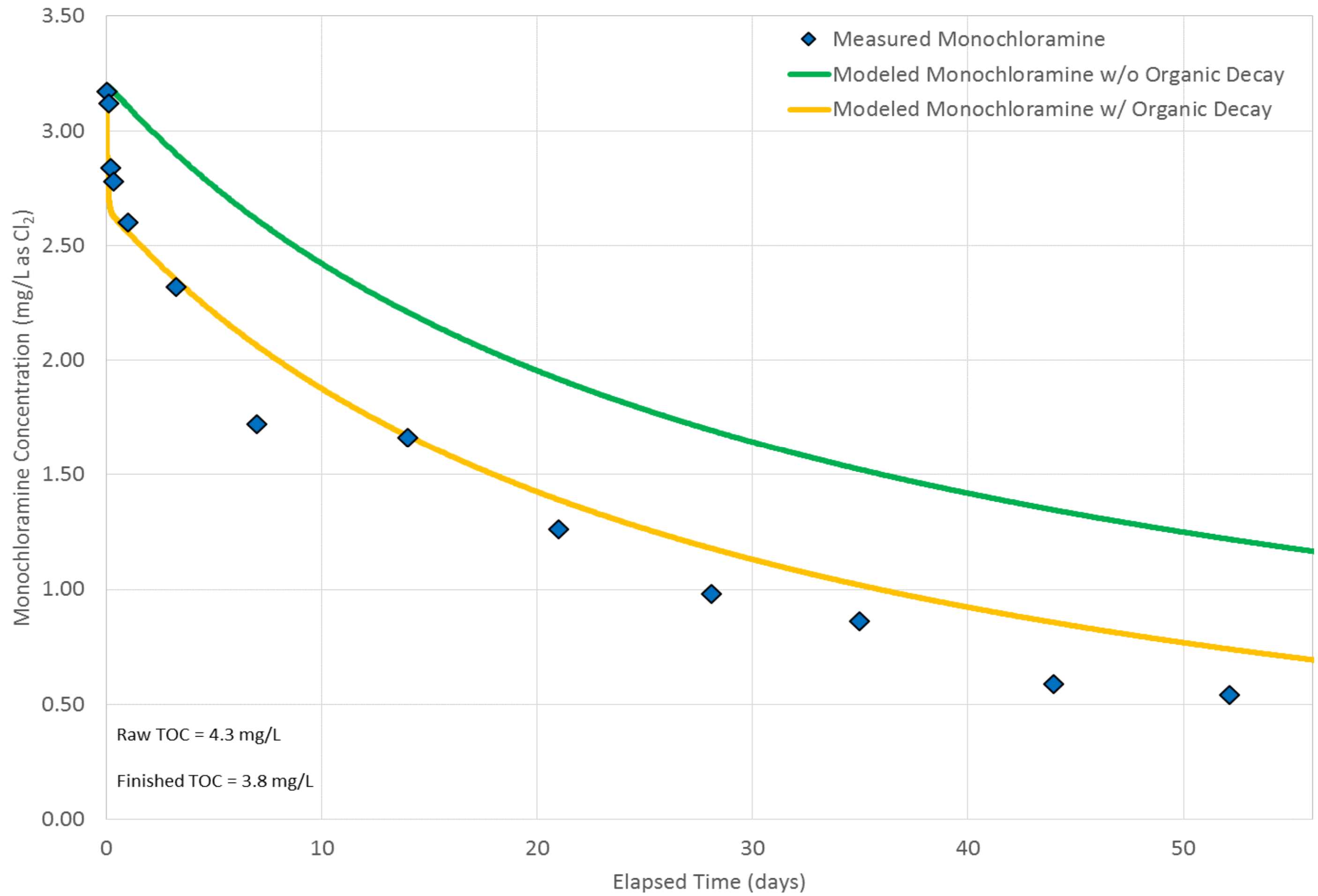
- Unstable water quality entering the distribution system can result in rapid decay in the distribution system
- This study can be used by an operator to assess water quality leaving the plant and stability
  - System influent water is collected in chlorine demand free bottles and maintained at distribution system temperature
  - Samples are collected periodically to simulate changes in water quality (e.g., chlorine decay, DBP formation)
  - Test generally offers conservative (optimistic) assessment of potential distribution system water quality

Hold Study Example: Free Chlorine Decay



- <u>Very low chlorine residual</u> entering the system combined with reactive water is not protective of public health!
- Chlorine residual below 0.20 mg/L in less than one day!

Hold Study Example: Impact of TOC on Monochloramine Decay



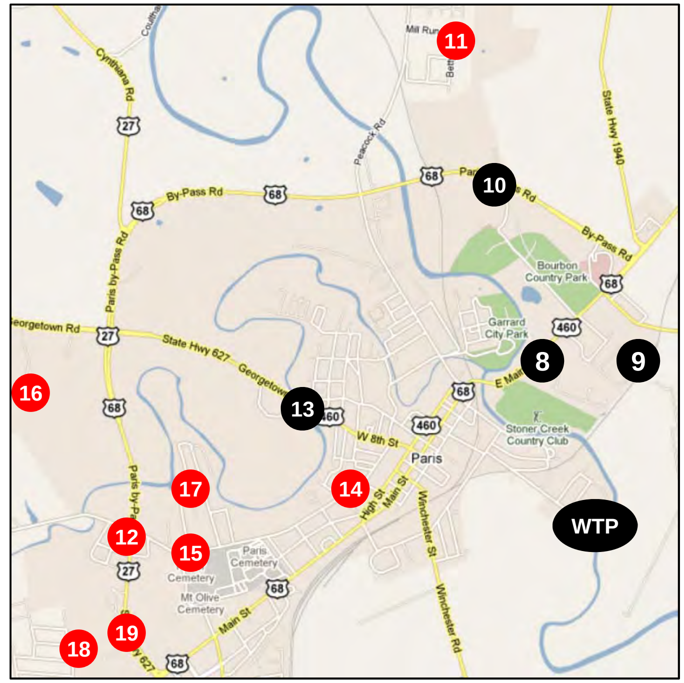
Chloramine Kinetic Model from Vikesland et al. (Water Research, 2001, 35 (7), pp 1766-1776)
Natural Organic Matter Decay Model from Duirk et al. (Water Research, 2005, 39 (14), pp 3418-3431)

Chlorine/Ammonia Dosing Control

- Maintaining a stable monochloramine residual in the distribution system begins in the plant
- Dosing the appropriate amount of ammonia with respect to chlorine is essential
  - The mass ratio of chlorine to ammonia-nitrogen (as Cl_2:N) should be between 4.5:1 and 5:1
  - Overfeeding ammonia increases the likelihood of nitrification in the distribution system
  - Underfeeding ammonia can result in the formation of dichloramine, which rapidly decays and may cause taste and odor issues

Chlorine/Ammonia Dosing Control

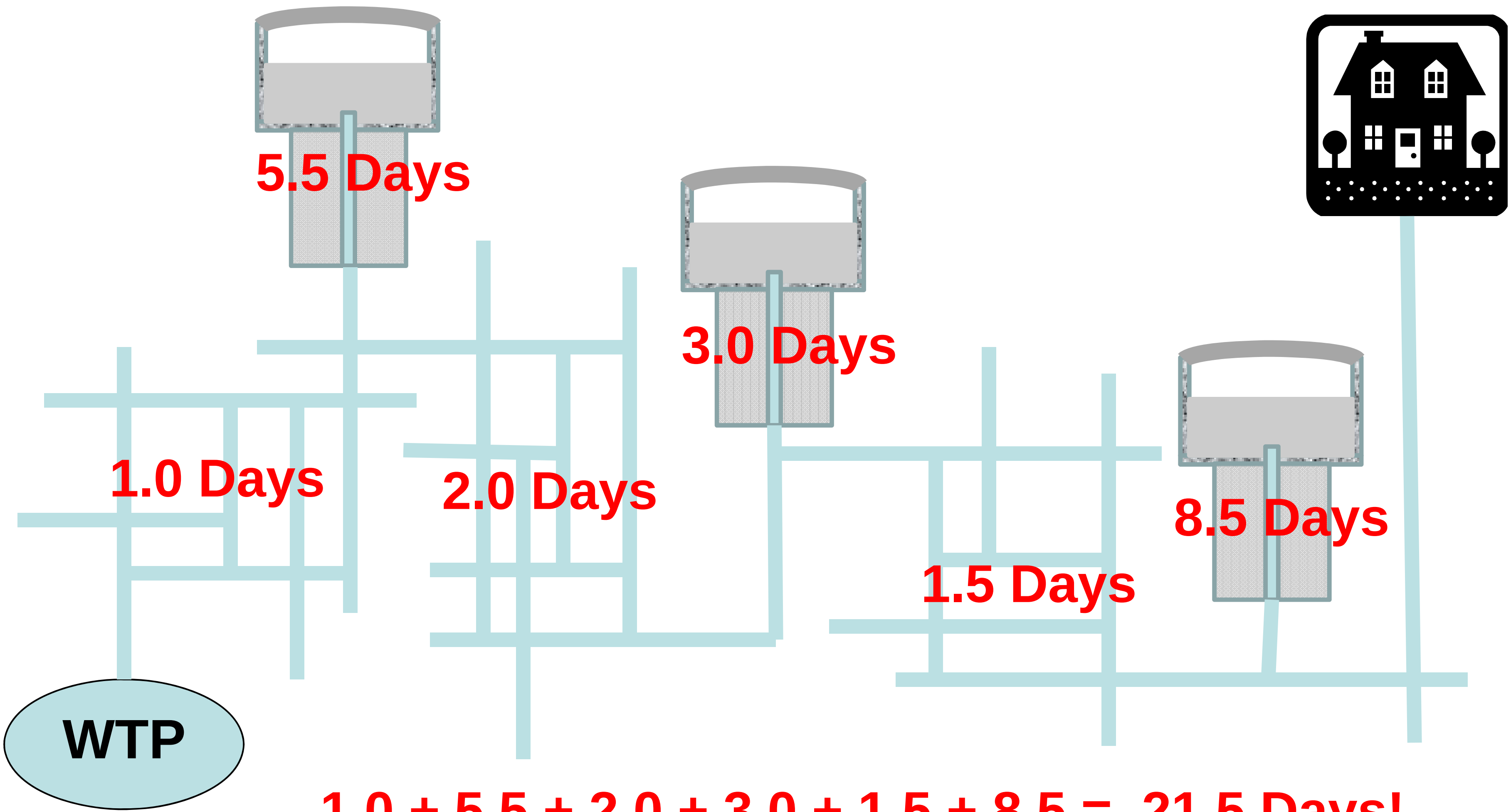
Sample Location	Total Chlorine mg/L as Cl_2	Monochloramine mg/L as Cl_2	Free Ammonia mg/L as N	Nitrite mg/L as N	Nitrate mg/L as N
WTP	3.03	2.87	0.33	0.010	0.008
11	0.11	0.11	0.06	0.010	0.050
12	0.34	0.11	0.19	0.204	0.176
14	2.9	2.34	0.47	0.009	0.021
15	1.6	0.44	0.48	0.101	0.009
16	0.70	0.50	0.44	0.047	0.333
17	0.70	0.28	0.46	0.135	0.855
18	0.28	0.20	0.26	0.070	0.280
19	0.43	0.13	0.29	0.262	1.278



Distribution System Optimization Monitoring

- Investigative sampling <u>throughout</u> the distribution system
  - Not limited to compliance locations
- Objective:
  - Characterize water quality throughout the entire distribution system.
    - o Is the residual barrier in-place?
    - o If not, where are the problem areas… and what improvement are optimization activities having on water quality?
  - Samples are collected in a consistent manner, to ensure data quality/integrity
  - Often data are “mapped” to show spatial trends

What Causes Excessive Water Age?



1.0 + 5.5 + 2.0 + 3.0 + 1.5 + 8.5 = 21.5 Days!

Storage Tanks: Overview and Case Studies

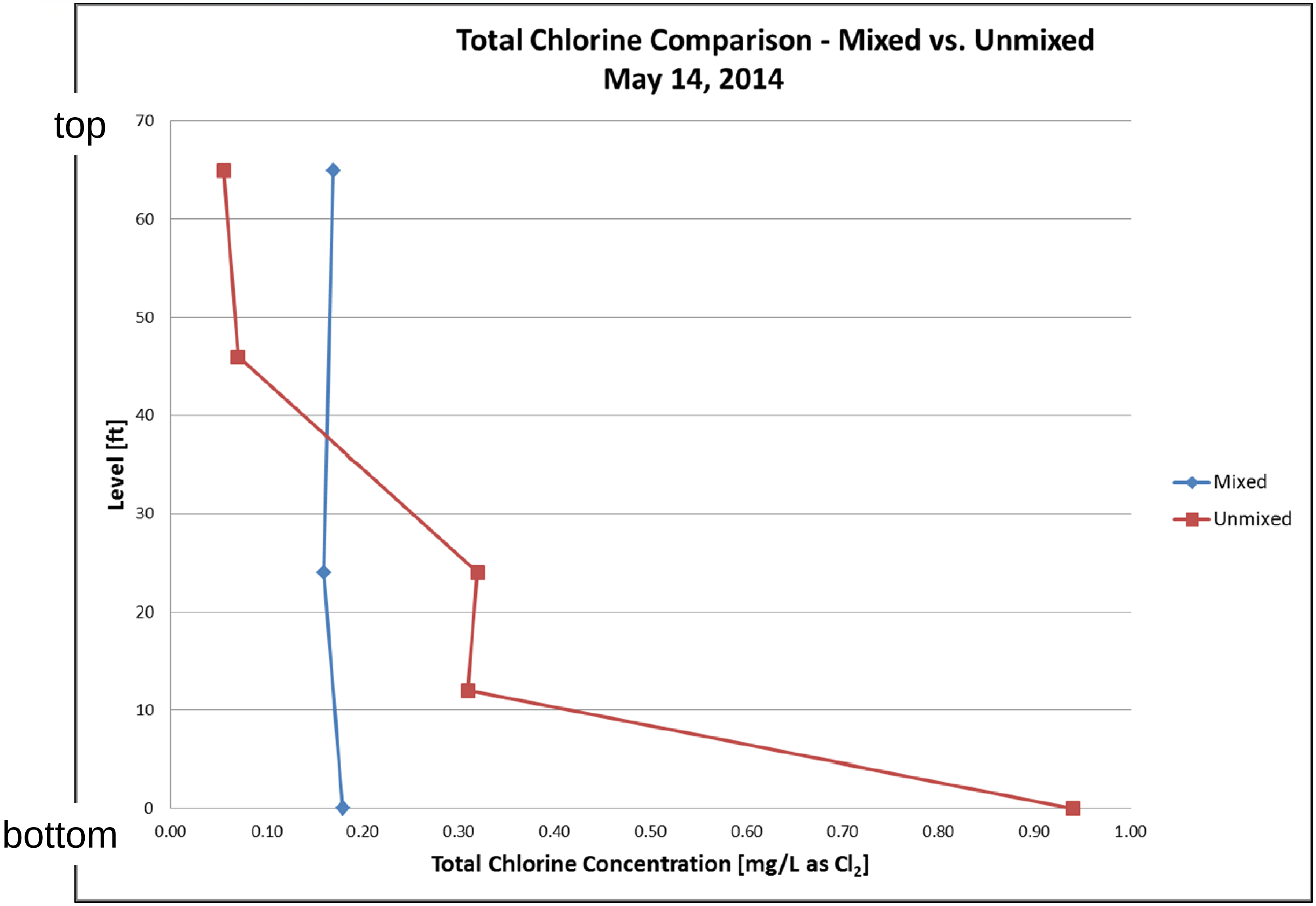
Storage Tank Impacts on Water Quality

- Water quality in storage tanks is influenced by both:
  - Turnover Time (or Water Age) – Average time that water is in a tank
  - Tank Mixing – A function of water velocity and duration of the fill cycle
- Storage tanks often contribute to poor water quality within the distribution system

Case Study #1: Pennsylvania

- Evaluated two side-by-side 0.26 MG ground level tanks
- The tanks were identical, but Tank #2 had a mechanical mixer and Tank #1 did not
  - Estimated Mixing Performance Ratio (Tank #1 only) = 0.33 (*>1.0 desired*)
- Estimated Average Turnover Time (Both Tanks) = 6.8 days

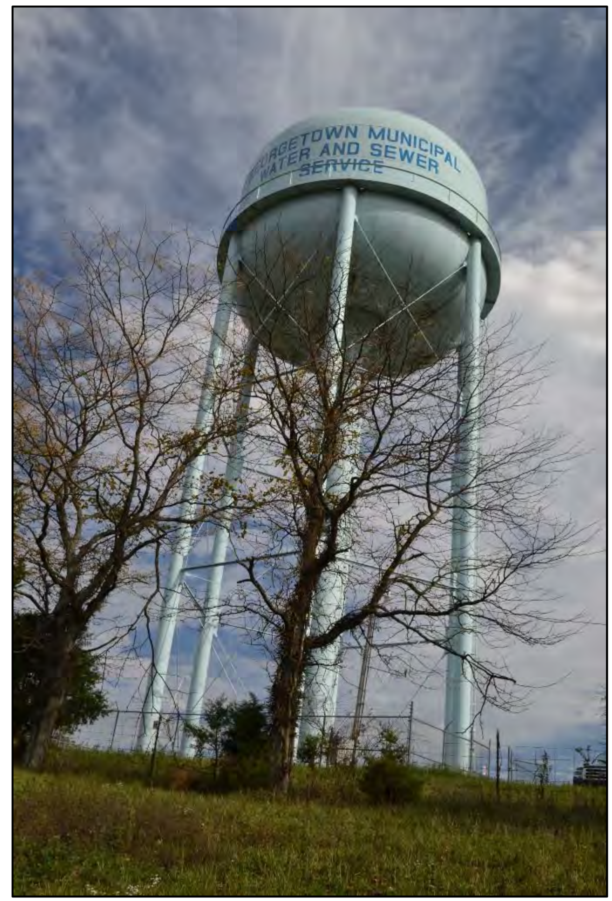
Case Study #1: Pennsylvania



Case Study #2: Kentucky

- Evaluated a 0.5 MG elevated tank with mechanical mixer
- Estimated Average Turnover Time = 1.4 days

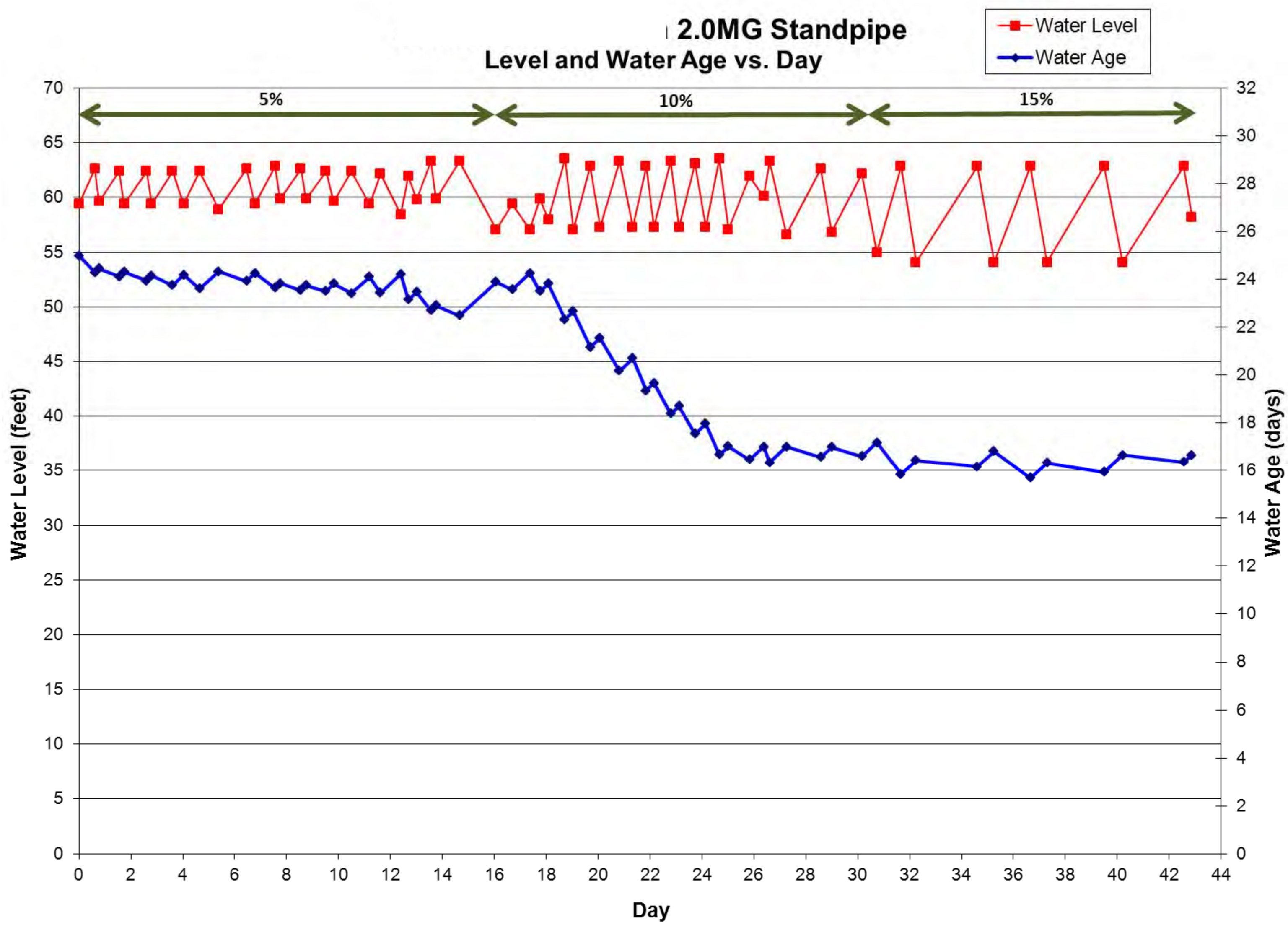
Sample Depth (from tank bottom)	Total Chlorine (mg/L as Cl_2)	Temperature (° C)
18’	2.10	15.2
13’	2.07	15.7
8’	2.03	15.9
3’	2.02	16.0
Bottom	2.04	15.7



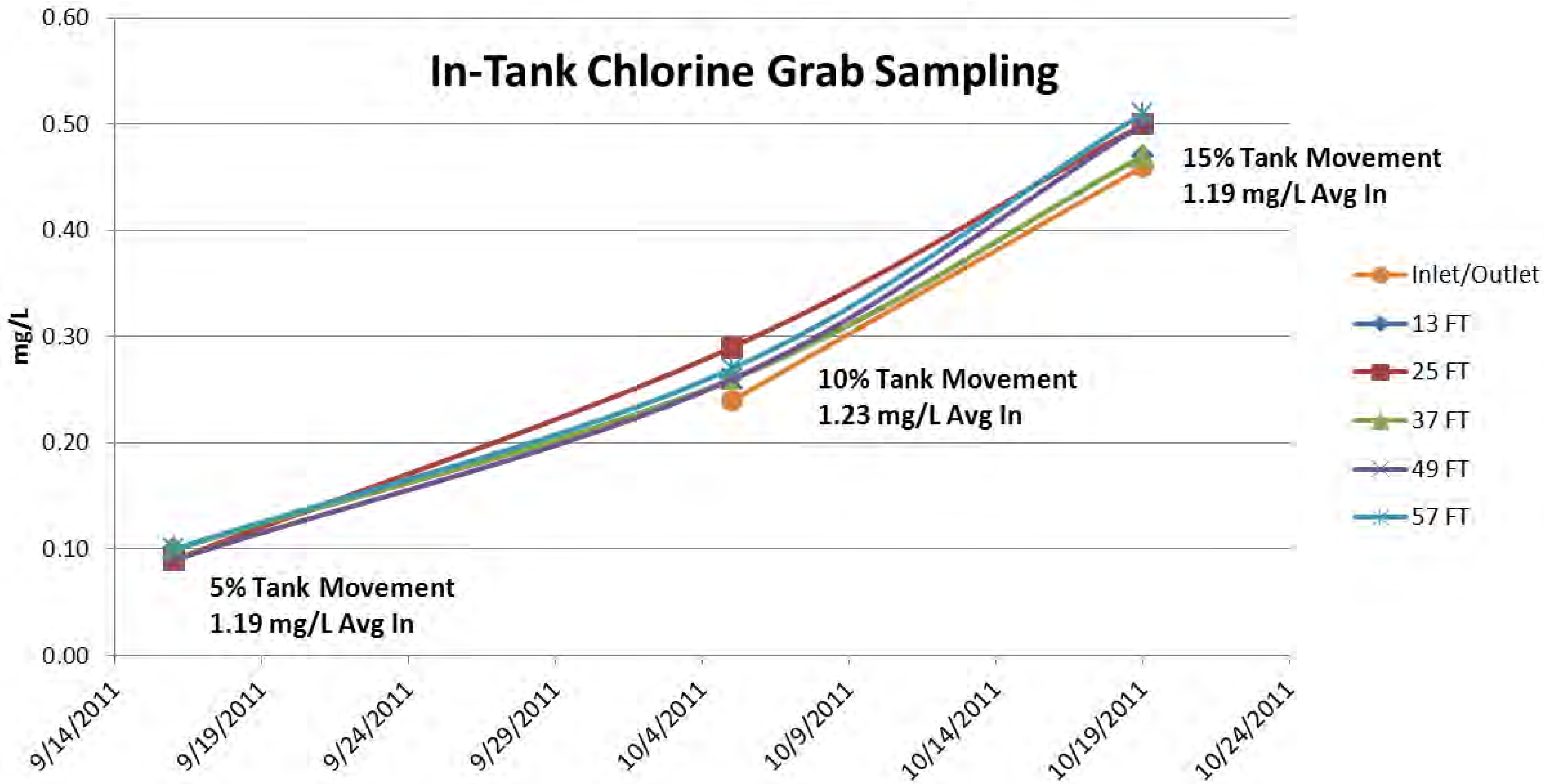
Potential Strategies to Reduce Turnover Time

- Operational Strategies:
  - Reduce Tank Volume: Operate tank at lower level(s) to reduce overall volume of water in the tank
  - Increase Fill-and-Draw Frequency, by increasing demand on the tank
- Design Changes:
  - Reduce volume in your distribution system
    - Remove tank(s) from service
    - Reduce line size (i.e., diameter)

Operational Change to Reduce Turnover Time



Operational Change to Reduce Turnover Time



Potential Strategies to Improve Mixing

- Operational Strategies:
  - Increase Operating Span, which will increase fill time (i.e., mixing time)
  - Change Fill Rate/Duration (i.e., same volume is added, but mixing intensity increases):
    - Faster rate over shorter time
    - Slower rate over longer time
  - Other Considerations:
    - Balance between these operational strategies
    - Stratification can prevent good mixing
    - Inlet/outlet location can make mixing impossible to achieve!
- Design Changes:
  - Engineered mixing system – baffling, static, or mechanical mixers.
  - Change inlet diameter to increase inlet velocity (flow rate)

Flushing: Overview and Case Studies

Flushing Overview

Criteria	Conventional	Unidirectional	Automatic	Blow Off
Approach	Reactive	Planned	Proactive	No other option(?)
Flush rate	Relatively high (>500 gpm)		Relatively low (20–75 gpm)	Varies
Labor/Travel Resources	Labor and travel resource intensive over several days		Initial installation and periodic maintenance	Initial installation
Water Quality Impact	One-time improvement, water quality eventually diminishes to pre-flush conditions		Cyclical improvement, water quality is monitored and maintained at desirable levels over an extended period of time	Likely improved but generally not measured
Flush Volume & Time	Relatively high		Relatively low	Continuous flow

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Flush Volume & Time	Relatively high		Relatively low	Continuous flow

Benefits of Implementing an Automatic Flushing Program

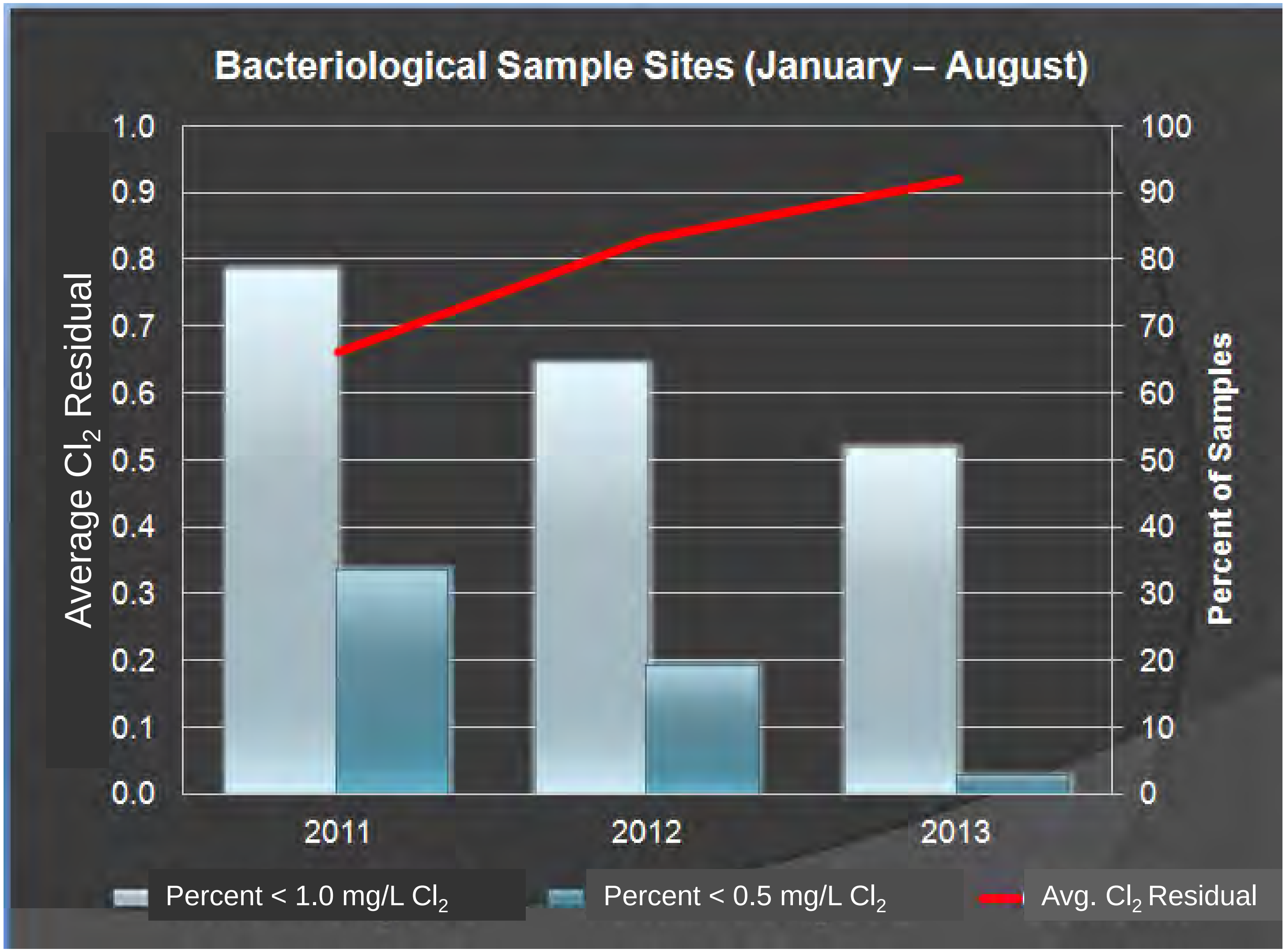
- Immediate water quality improvement due to reduced water age (a.k.a. “artificial demand”) in the distribution system
  - Increases chlorine residual
  - Decreases disinfection by-products
  - Reduces customer complaints associated with taste, odor, and color
  - Nitrification prevention/control strategy
  - Removes accumulated sediment and biofilm (applies to higher velocity flushing, >5 ft/sec)
- Time (man hours) savings with auto flushers
- Two systems have implemented auto-flushing programs that have made a difference in water quality

Case Study #1: Alabama

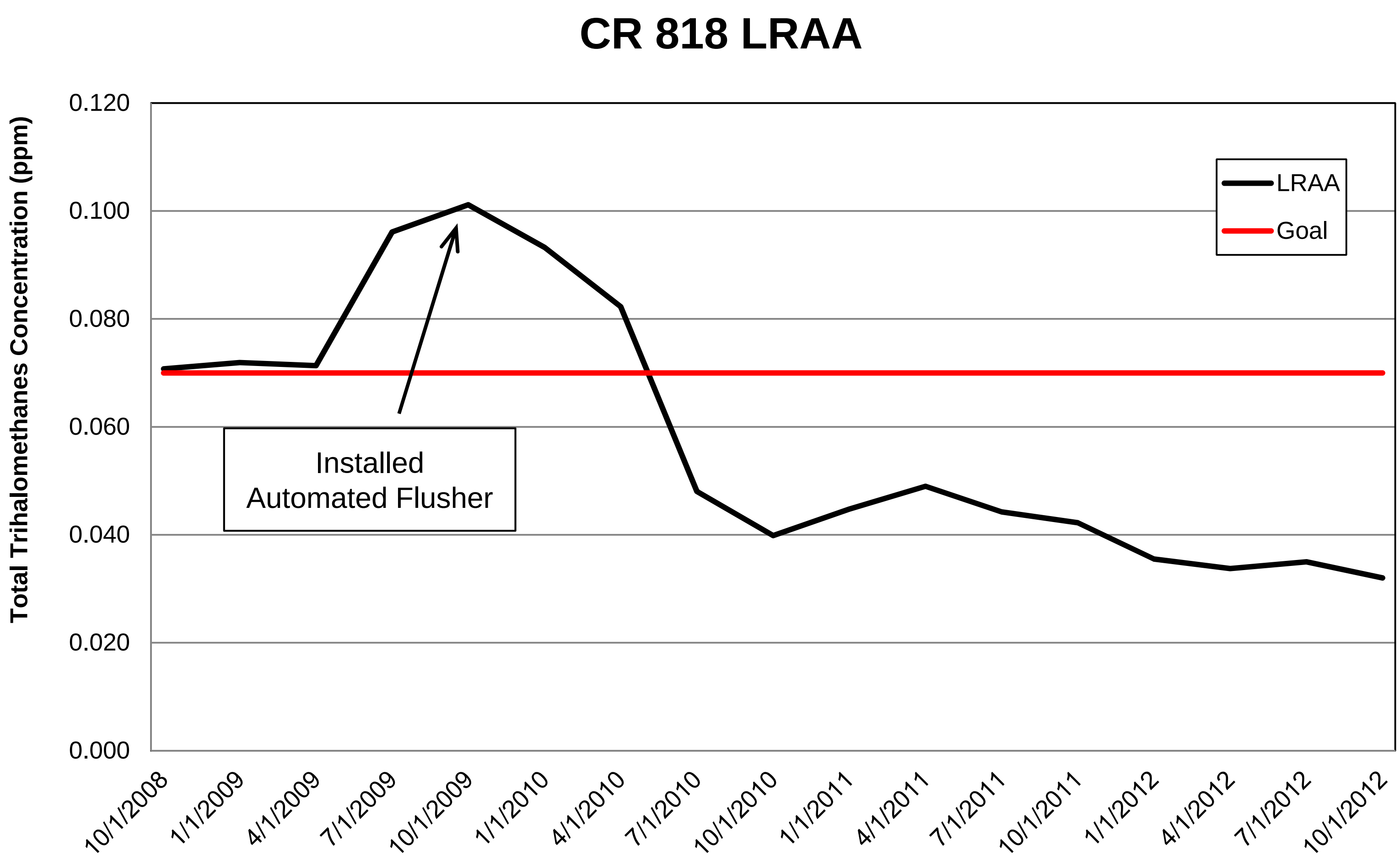
Free Chlorine Consecutive System (Purchase-Only)

Automated Flushing Program Usage Data	
Number of Automated Flushers	14
Customer Connections	≈ 5,000
Average Monthly Purchase	38,630,000 gal
Average Accounted Water Loss (located leaks, etc.)	2,548,000 gal (6.6%)
Average Unaccounted Water Loss	5,152,000 gal (13.3%)
Average Volume Automatically Flushed	199,000 gal (0.5%)

Case Study #1: Alabama

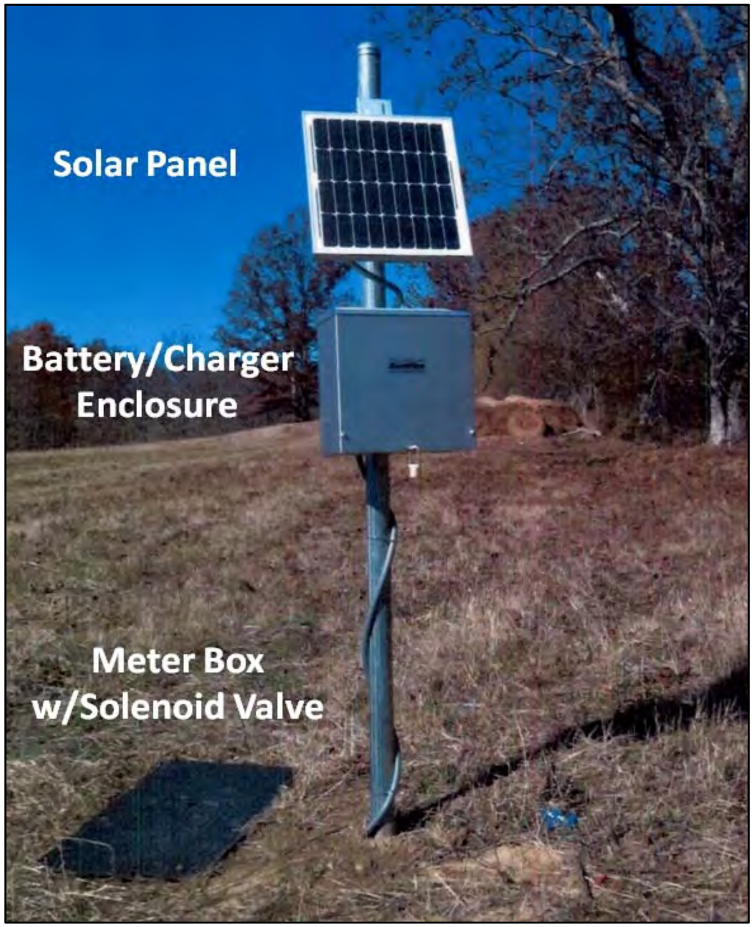


Case Study #1: Alabama



Case Study #2: Kentucky

- Chloraminated parent (producing) system
- Program initiated in 1992
- Total cost: ≈$2000/flusher
- Return on investment for solar power: ≈10 years
- Building code for new developments requires installation of automated flushing valve
- Viewed by administration as "the cost of doing business"

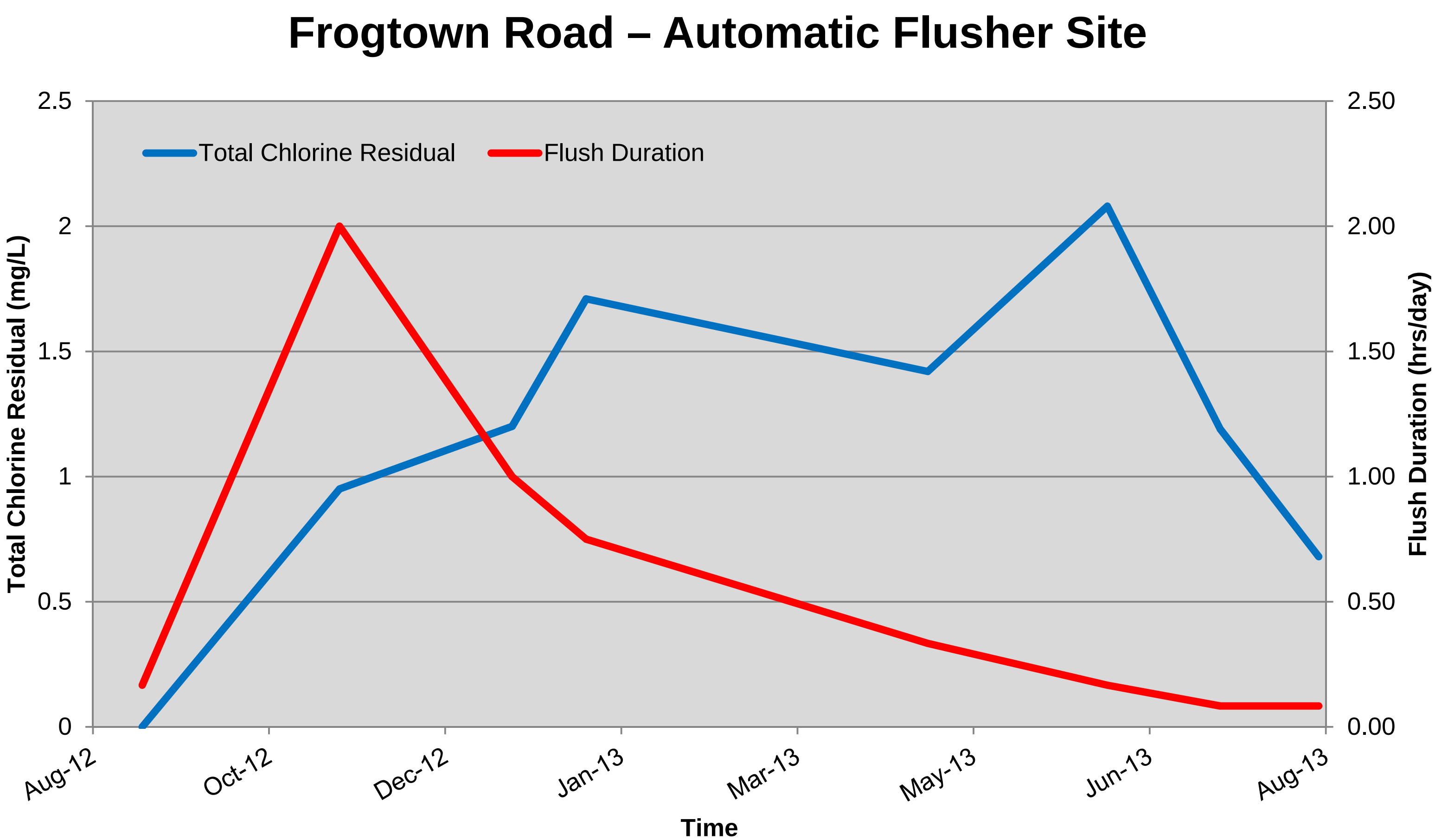


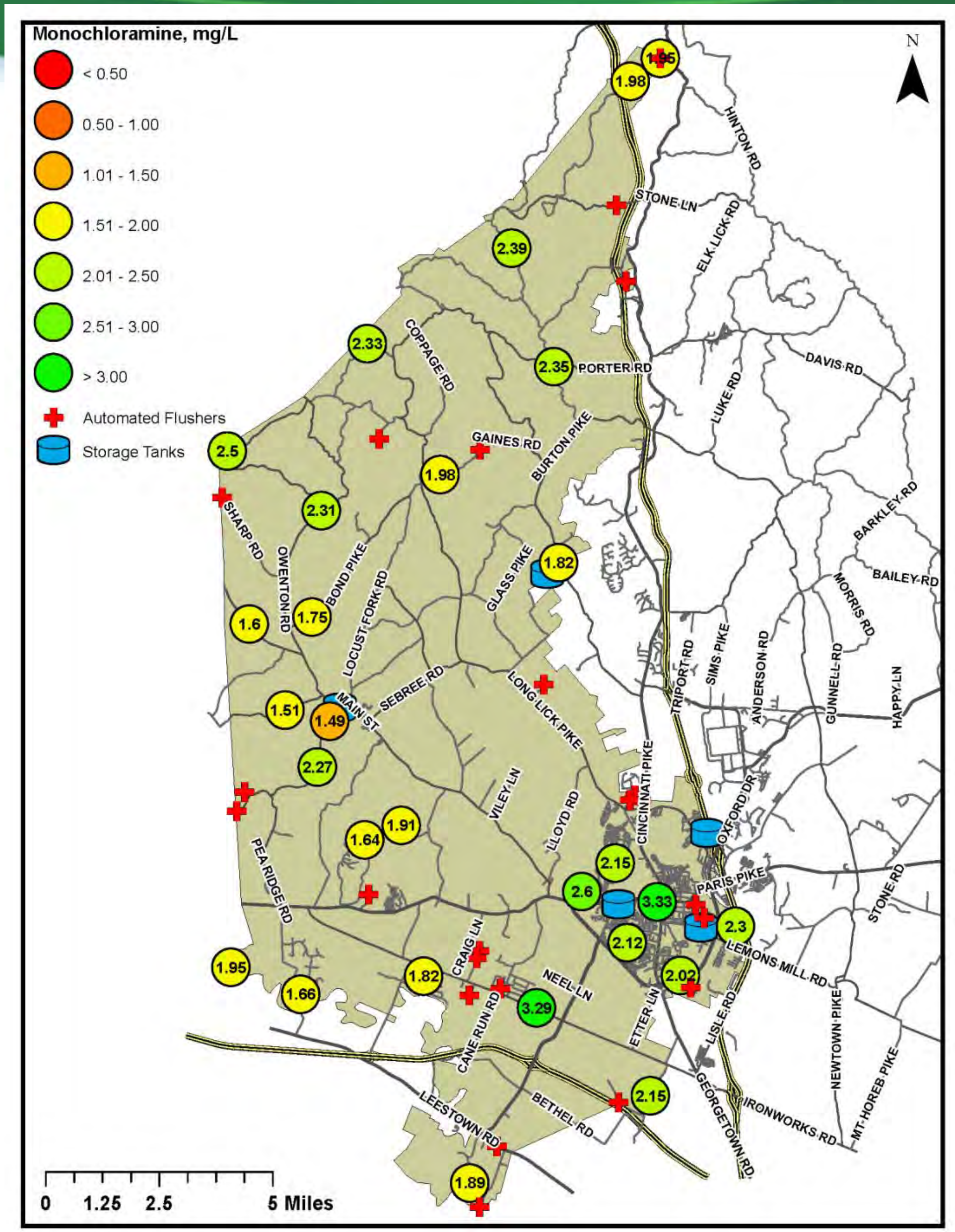
Visit http://www.gmwss.com/specs/WaterDetails.zip for more details.

Case Study #2: Kentucky

Automated Flushing Program Usage Data	
Number of Automated Flushers	24
Customer Connections	≈ 12,000
Average Monthly Purchased and Produced	214,102,793 gal
Average Accounted Water Loss (located leaks, etc.)	16,434,990 gal (6.25%)
Average Unaccounted Water Loss	32,663,931 gal (12.8%)
Average Volume Automatically Flushed	5,458,920 gal (2.07%)
Average Volume Manually Flushed	814,275 gal (0.30%)

Case Study #2: Kentucky





Case Study #2: Kentucky

- Sampling study conducted in the summer of 2011
- Maintained monochloramine residual above 1.5 mg/L throughout the entire system
- No evidence of nitrification

Flushing: Parting Thoughts

- Systems ALWAYS meter flushed volume and determine automated flusher settings based on water quality
- Flushing often thought of as “the cost of doing business” but…
- Could a parent system:
  - Provide flushed water at cost to the consecutive system?
  - Consider providing some volume of water at no cost to consecutives (AWOP encourages “one big system” among parent & consecutive systems)?
- Flushed volume typically few percent of produced/purchased volume

Rerouting Water

- Very system specific, but can be effective
- Changes how water moves through the system through combination of valving and rerouting
  - Example: Through an area of low demand to end up at a high demand customer (e.g., dog food factory) ☺
  - Example: System has parallel lines for fire protection; valve/force water through larger line (serves hydrants) through smaller line (residential demand) to keep water moving
- May move problem from one area to another
- Often "artificial demand" (flushing) may still be needed

Summary

- The AWOP utilizes optimization based approaches to impact water quality at the consumers' tap
  - Water quality goals and guidelines have been established
  - Optimization tools are used to evaluate water quality
  - Optimization strategies have successfully improved/maintained distribution system water quality
- Optimization investment typically includes staff time for monitoring and implementing strategies
- Optimization may not be the solution for every system, but should be a starting point for all systems striving to improve distribution system water quality

Acknowledgements

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- Kentucky Divison of Water (KYDOW) & participating systems
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Questions?

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