Reducing Disinfection Byproducts through Optimization

Webinar #3: Approaches to Prioritize Distribution System Optimization Efforts

May 6, 2019

Webinar Series

- Primary Learning Objective: Introduce participants to disinfection byproduct (DBP) optimization tools that can be used to reduce DBPs in public water systems. These tools have been developed in partnership with state drinking water programs through the Area Wide Optimization Program (AWOP).
- Four successive webinars:
  - ~~April 8th – DBP Optimization Process and Priority Setting~~
  - ~~April 22nd – Approaches to Prioritize Plant Optimization Efforts~~
  - **May 6th – Approaches to Prioritize Distribution System Optimization Efforts**
  - May 13th – Implementing DBP Control Strategies: Approach and Case Studies

Webinar Series Logistics

- All webinars will be scheduled for 1:30 pm ET, will take about 2 hours (including Q&A), and will be recorded.
- Register for EACH webinar individually through ASDWA.
- Viewers can submit questions via the Questions Panel at any time during the broadcast. A Q&A session will be held at the end of all the presentations.

Webinar #3: Learning Objectives

- Understand overall approach for the webinar series, including a brief review of information covered in the previous webinars
- Understand approaches and tools used to prioritize available distribution system DBP control strategies
  - Approaches to evaluate distribution system water quality and applicable control strategies (Presentation 2).
  - Overview of water storage tanks, including tank characteristics and how they impact water quality, as well as potential tank studies such as estimating turnover time and mixing characteristics and sampling in/around tanks to assess water quality (Presentation 3).

Disclaimer

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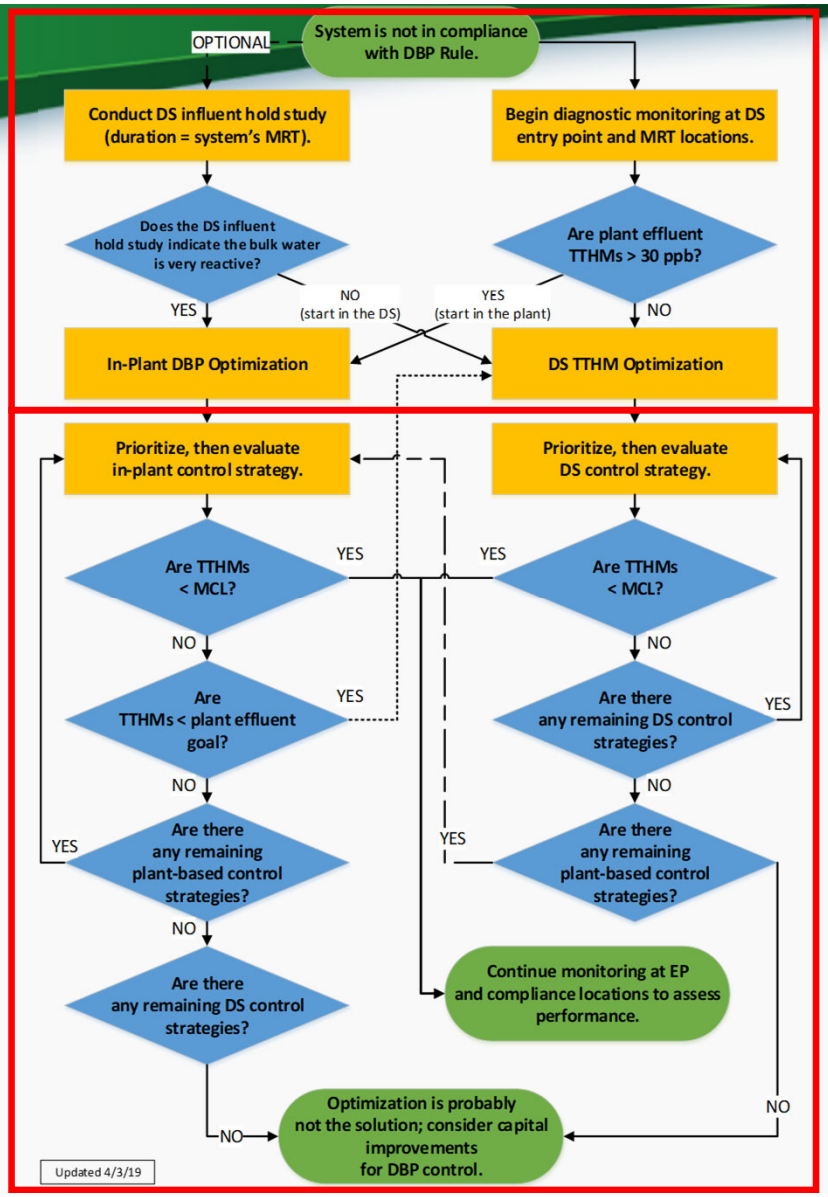
Process to Reduce DBPs through Optimization: Review

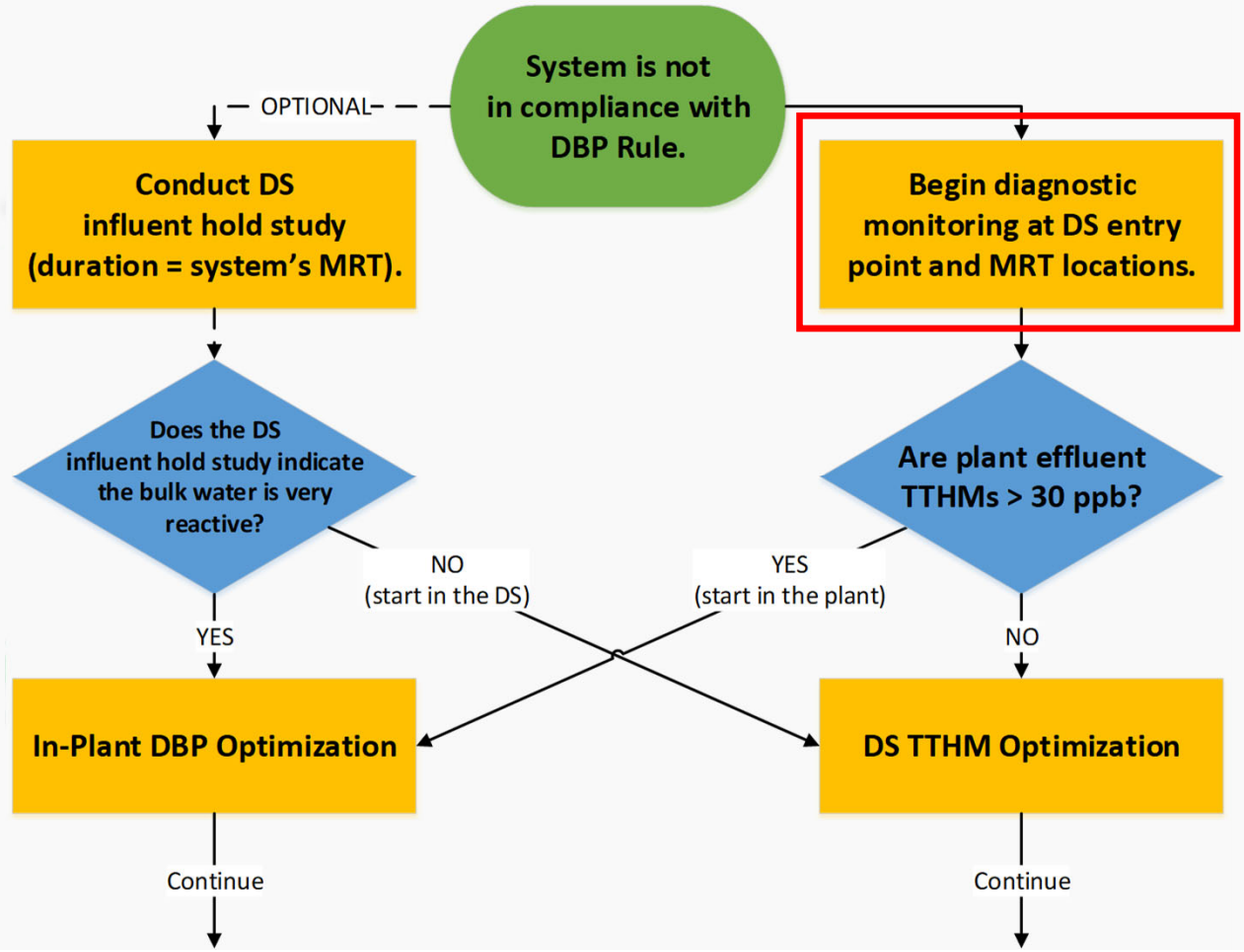
Process to Reduce DBPs through Optimization

Note: in-plant optimization efforts can be effective for both HAA5 and TTHM reduction, while distribution system (DS) optimization efforts will generally only reduce TTHM levels.



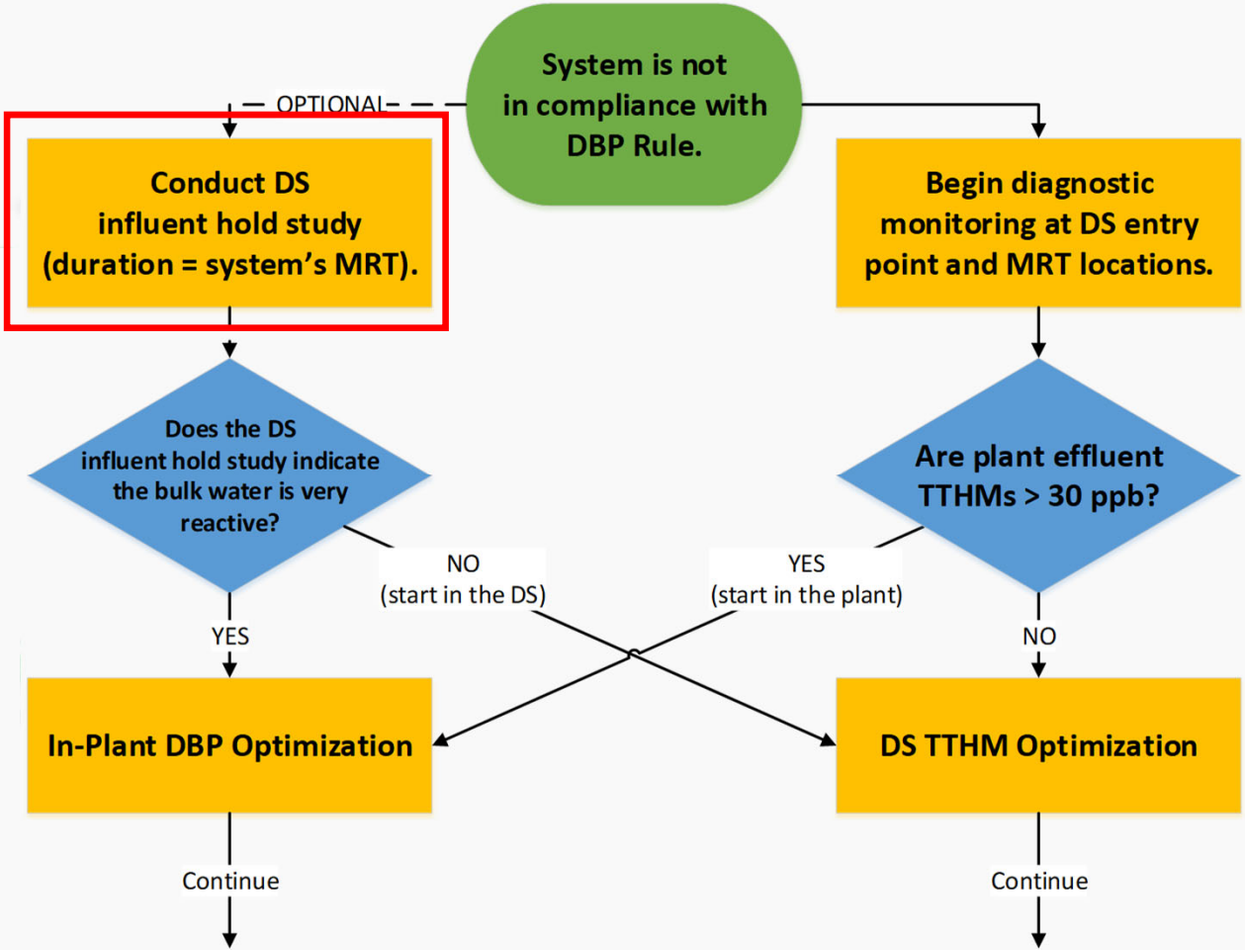
Diagnosing DBP Formation

First step is to conduct diagnostic monitoring



Diagnosing DBP Formation

Optional step to conduct a DS influent hold study



Diagnosis ➔ Start in the Distribution System

- Plant effluent TTHMs < 30 ppb*
- Diagnostic sampling shows significant TTHM formation between DS EP & MRT
- Hold study shows:
  - Disinfectant residual is fairly stable
  - MRT TTHMs (hold study) **<** Stage 2 MRT TTHM

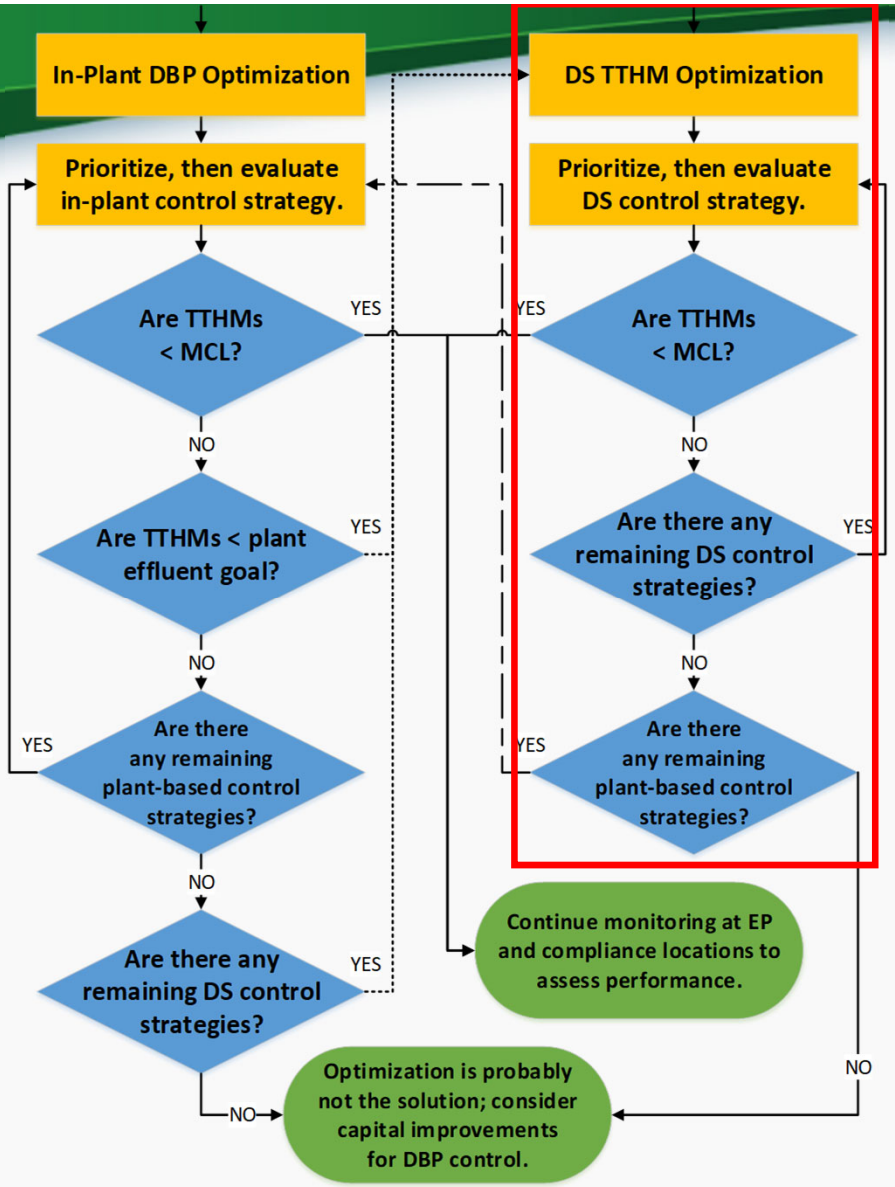
→ **DS optimization** focused on tanks, flushing, and hydraulics

**This is system specific, but, based on field experience, an optimized plant can likely produce DBPs below this level.*

Evaluating Distribution System Control Strategies

Focus of Webinar #3

- Overview presentation on distribution system control strategies
- Presentation on water storage tanks



DS Options to Reduce DBP Formation

- Primary strategy is to **reduce water age,** through:
  - Implementing a flushing program
  - Managing Tanks
  - Modifying system hydraulics
- Also, treatment and minor design changes may be needed
- Can be utilized by parent and consecutive systems
- Consider unintended consequences related to making DS adjustments

Evaluating DS Control Strategies:
Unintended Consequences

- Once prioritized, evaluate strategy(s) considering unintended consequences and associated resources of distribution system adjustments. Examples include:
- Customer complaints, such as:
  - Discolored water may result from flushing or changing flow patterns
  - Anti-conservation perceptions (e.g., flushing)

Example Unintended Consequences of DS Control Strategies

- Impacts related to modifying system hydraulics:
  - Reduced capacity for peak demands
  - Low water pressure due to reduced tank levels
  - Concerns with removing tanks from service
  - Additional wear on pumps due to fill cycle changes
  - Potential hydraulic challenges associated with rerouting water
- Others??

Resource Considerations Related to DS Control Strategies

- Costs associated with:
  - Installing and operating treatment and/or design changes
  - Tank maintenance services
  - Development and implementation of unidirectional flushing program
- Staff time
- Revenue lost due to unbillable water (e.g., flushing)
- Others?

Distribution Control Strategies

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Distribution Control Strategies

- Holistic System Flushing
- Tank Turnover – Operational Changes
- Rerouting Water
- The Unexpected

Holistic System Flushing

Benefits of a 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
- Removes accumulated sediment and biofilm (applies to higher velocity flushing, >5 ft/sec)

Flushing Manual vs Automatic

Manual – Trained Cats

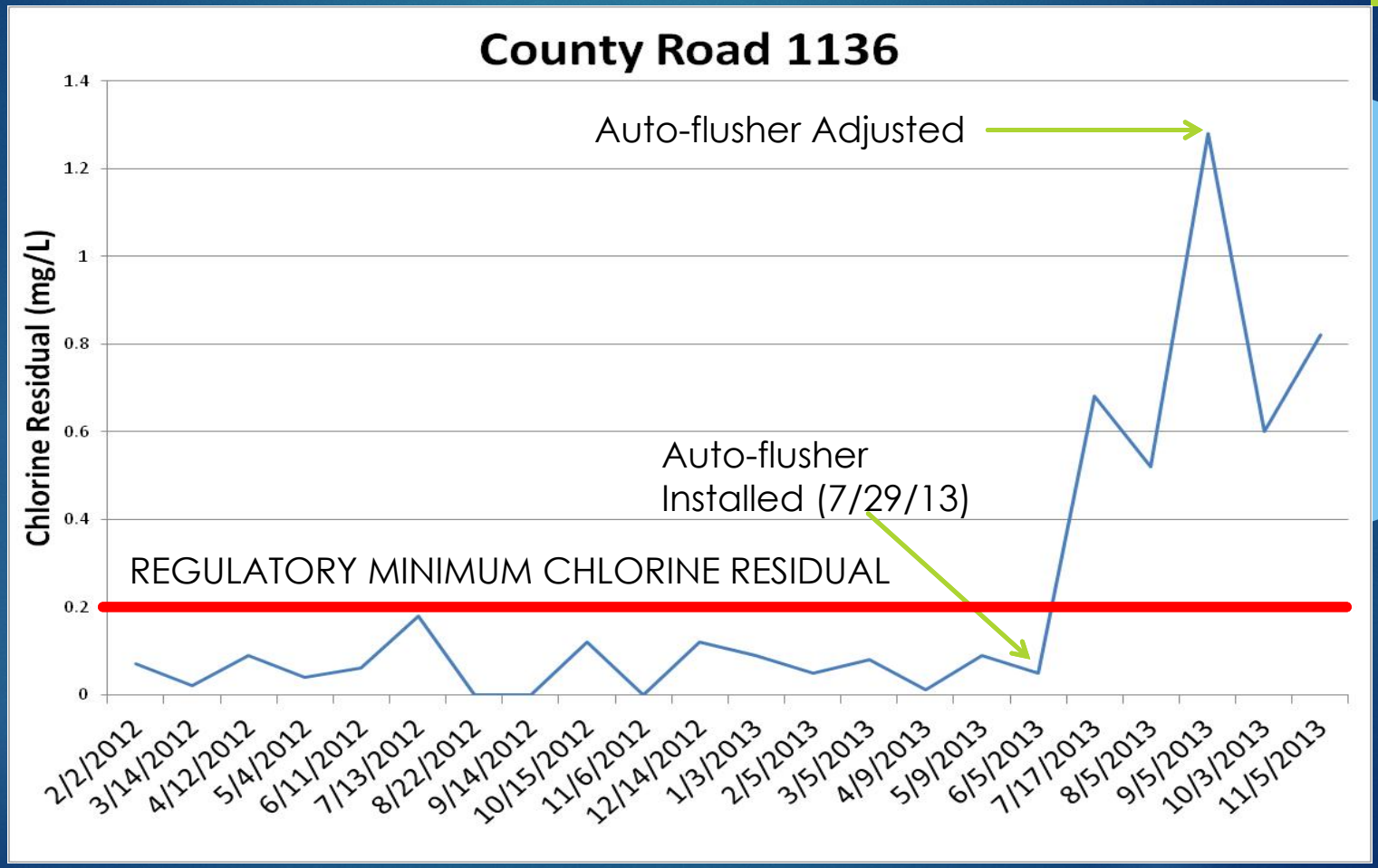
Automatic

This presentation does not endorse or support any product shown or discussed. Additionally no animal was actually used to flush a water system.

Holistic Automatic Flushing Program

- System
  - 15,000 Population (5,100 Customers)
  - 550 miles of water main
  - 2 sources of water
  - Rural purchase water system covering parts of three counties
  - Two booster chlorination stations
  - 20 small automatic flush stations

Chlorine Residual Restoration



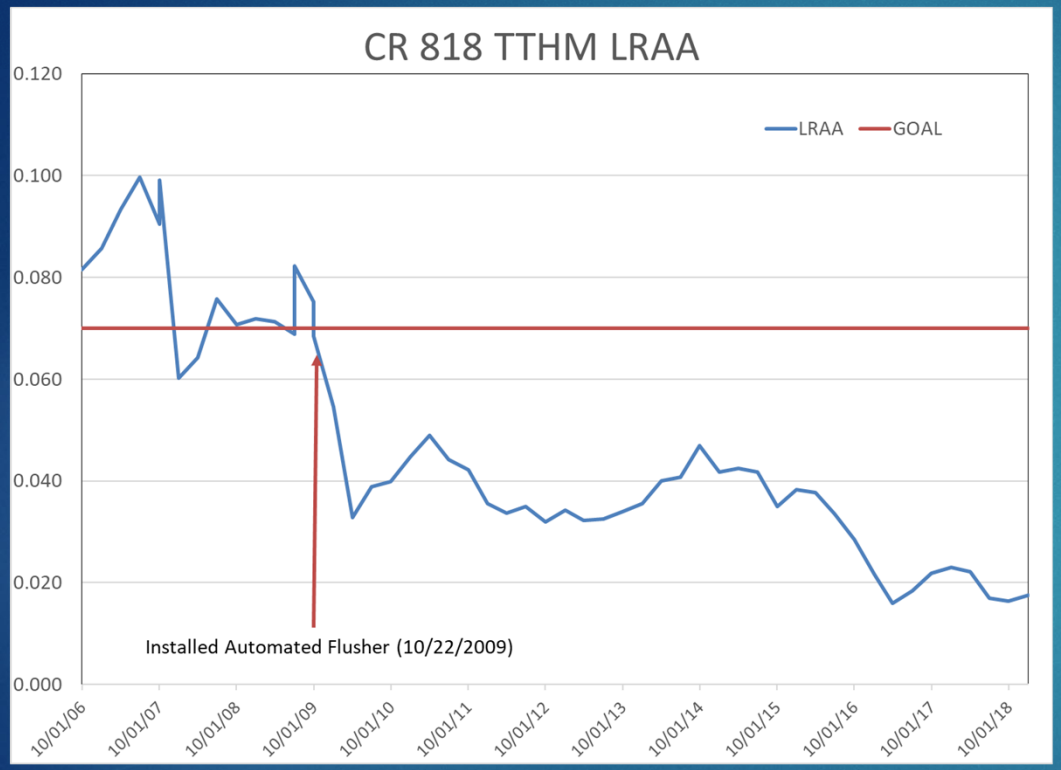
Continuous Monitoring of Flush Station (CR 1136)

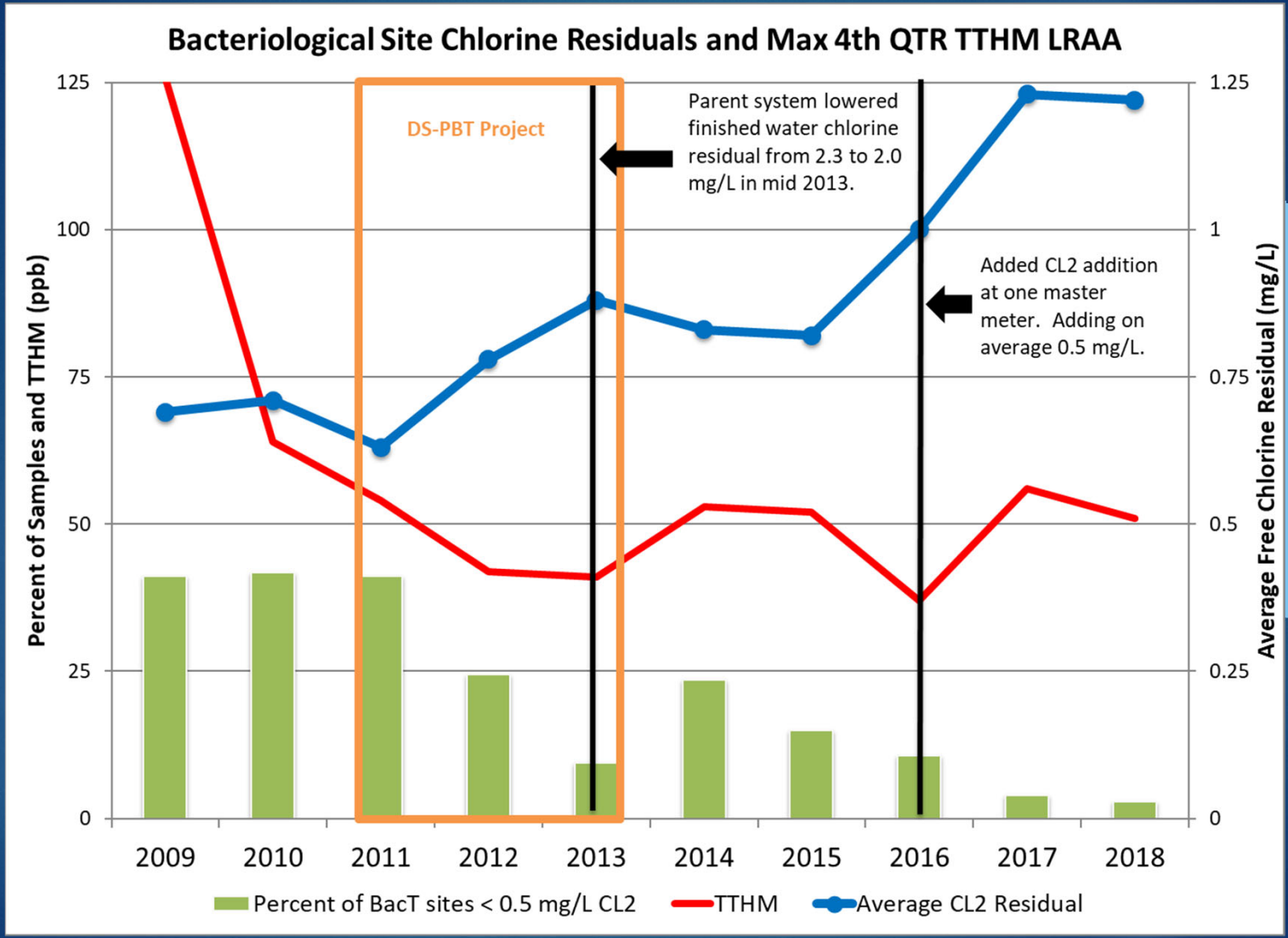
MONITORING FOR DBP SAMPLING — 6" HYDRANT END OF LINE

ACCT#12-6190 — CO RD 1136

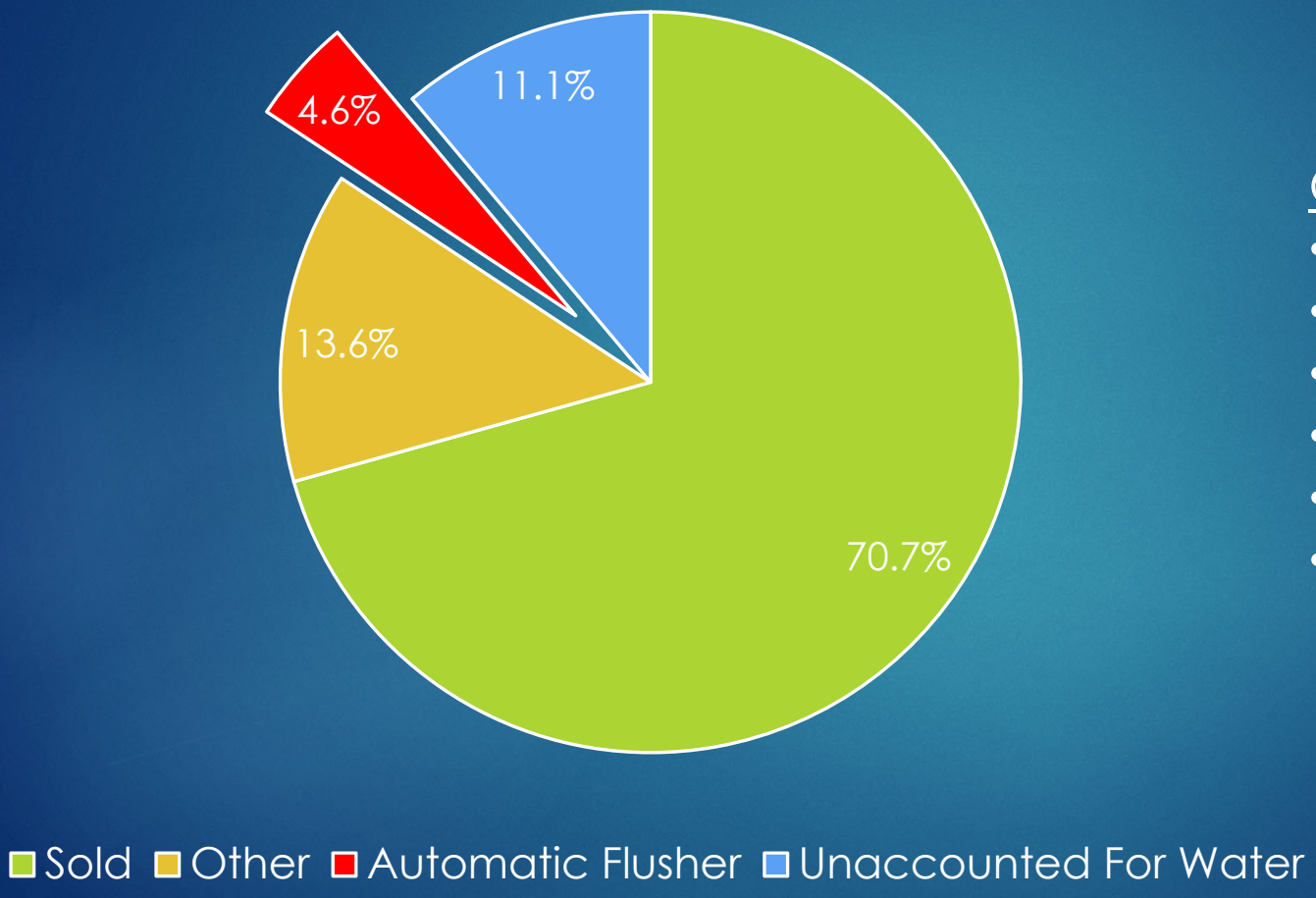
DATE	CHLORINE BEFORE	WATER TEMP	CHLORINE AFTER	TIME FLUSHED	GALLONS FLUSHED	WATER SOURCE	READING	USAGE	Setting Verified or Changed To	NOTES	BY
										Installed Automatic Flush Meter 6-12-2013	
							2402				
1/6/2014					124,700	CITY	3649	124700	MTTS-4HRS	NO CHANGES-FROZEN CANT GET RESULTS	PS
2/5/2014		49.4	1.13		85,400	CITY	4503	85400	smwf-4hrs	take off Sunday	PS
3/5/2014		53.7	0.75		75,500	CITY	5258	75500	mwf-4hrs	no changes	ps
4/3/2014		59.3	0.82			CITY			mwf-4hrs	ps-wl checked	
4/4/2014		61.7	0.89		106,800	CITY	6326	106800	mwf-4hrs	no changes	PS
5/6/2014		68.1	0.54		116,200	CITY	7488	116200	mwf-4hrs	add Wednesday	wl
5/8/2014						CITY			mtwts-4hrs	sw checked settings	sw
6/4/2014		77	0.54		166,200	CITY	9150	166200	mtwts-4hrs	no changes	ps
7/7/2014		83.3	0.31		198,300	CITY	11133	198300	mtwts-4hrs	add Thursday	PS
8/6/2014		84.2	0.64		146,000	CITY	12593	146000		no change	PS
8/11/2014						CITY			mtwtfs-4hrs	checked settings	wl-sw
9/5/2014		84.2	0.62		211,400	CITY	0-2114	211400	mtwtfs-4hrs	no changes	ps
10/6/2014		77.1	0.60		216,600	CITY	4280	216600	mtwtfs-4hrs	no changes	PS
11/6/2014		64.7	0.30		206,300	CITY	6343	206300	smtwtfs-4hrs	add Sunday	wl
12/4/2014		58.2	0.88		234,400	city	8687	234400	smtwtfs-3hrs	took off 1 hr flush time	wl

Effect of small flusher on TTHMs.




Bacteriological Site Chlorine Residuals and Max 4th QTR TTHM LRAA
Percent of Samples and TTHM (ppb)
Average Free Chlorine Residual (mg/L)
125
100
75
50
25
0
1.25
1
0.75
0.5
0.25
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
DS-PBT Project
Parent system lowered finished water chlorine residual from 2.3 to 2.0 mg/L in mid 2013.
Added CL2 addition at one master meter. Adding on average 0.5 mg/L.
Percent of BacT sites < 0.5 mg/L CL2
TTHM
Average CL2 Residual

Distribution of Water Purchased



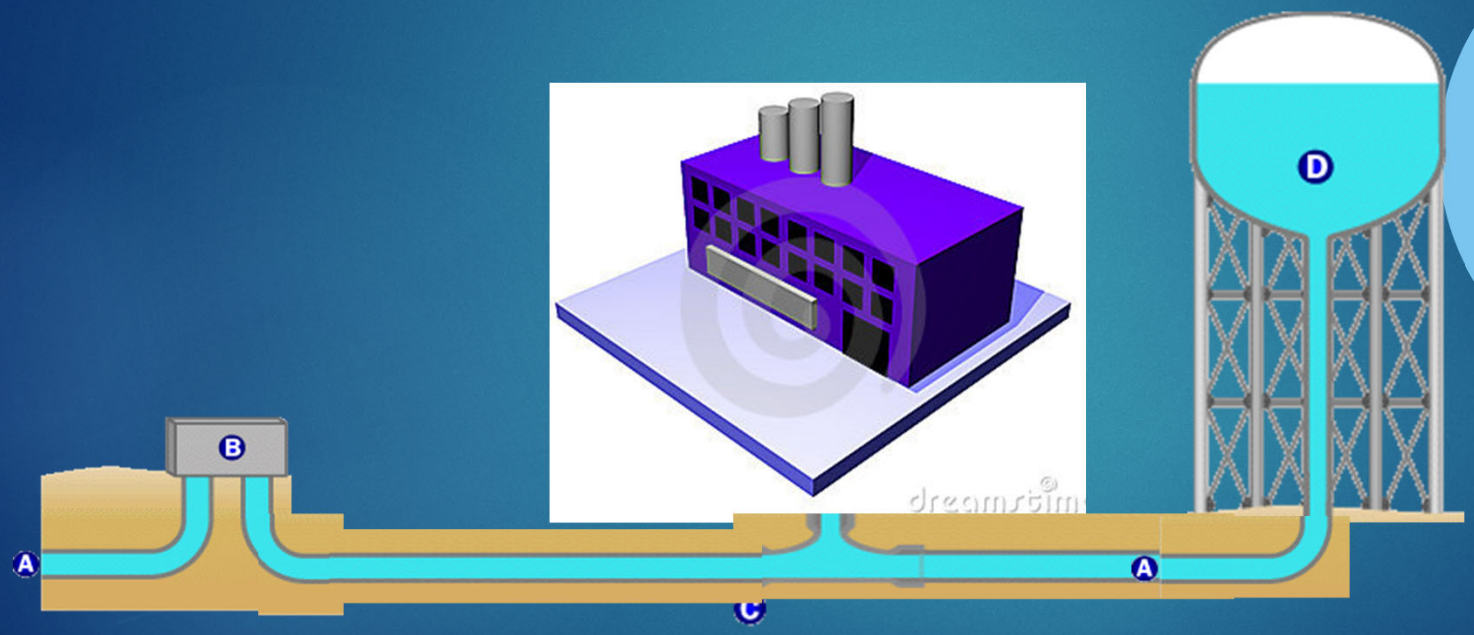
Other Water Includes

- Line Flushes
- Service Leaks
- Main Leaks
- Contractors
- Fire Departments
- Road Departments

Data from
April 2018 – March 2019

Tank Turnover – Operational Changes

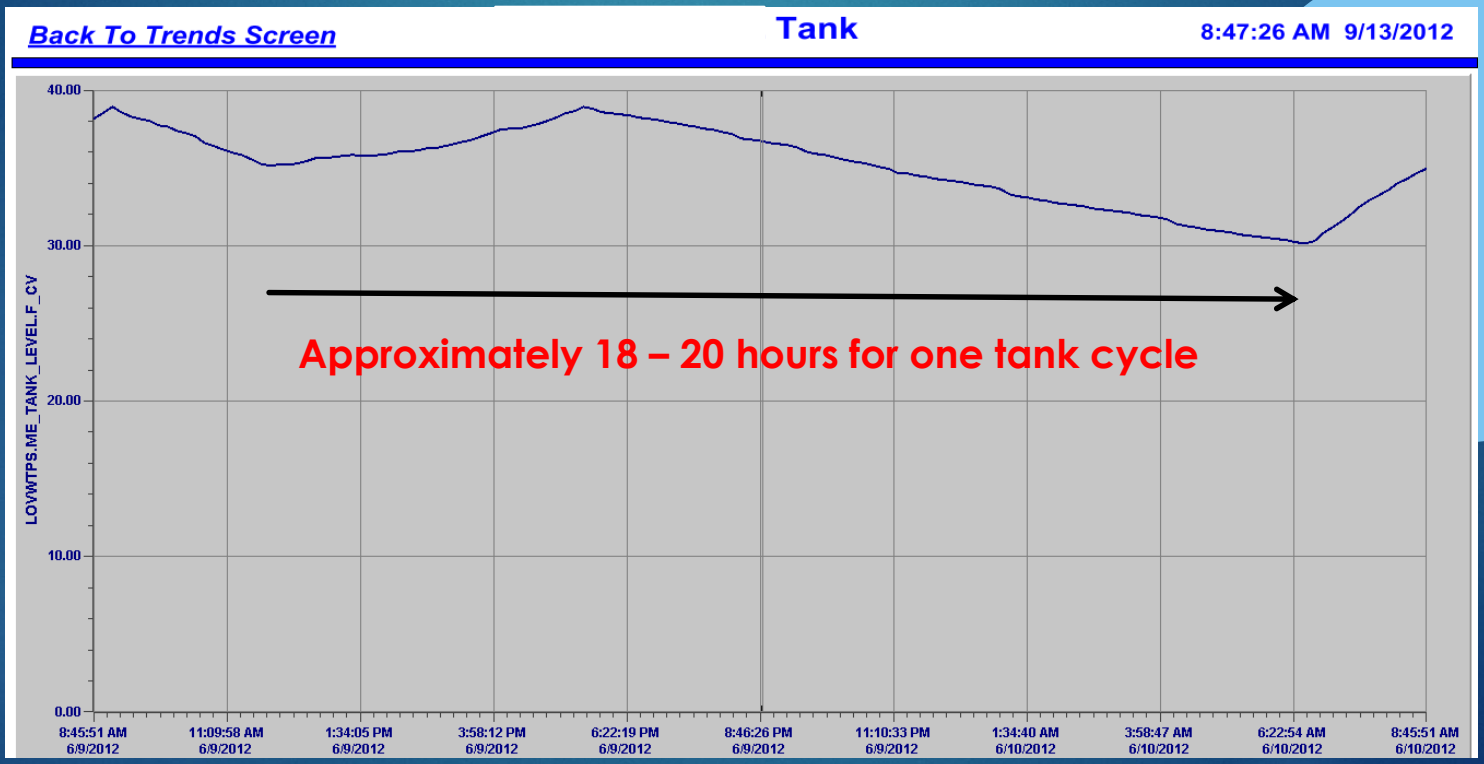
Pump Station Change



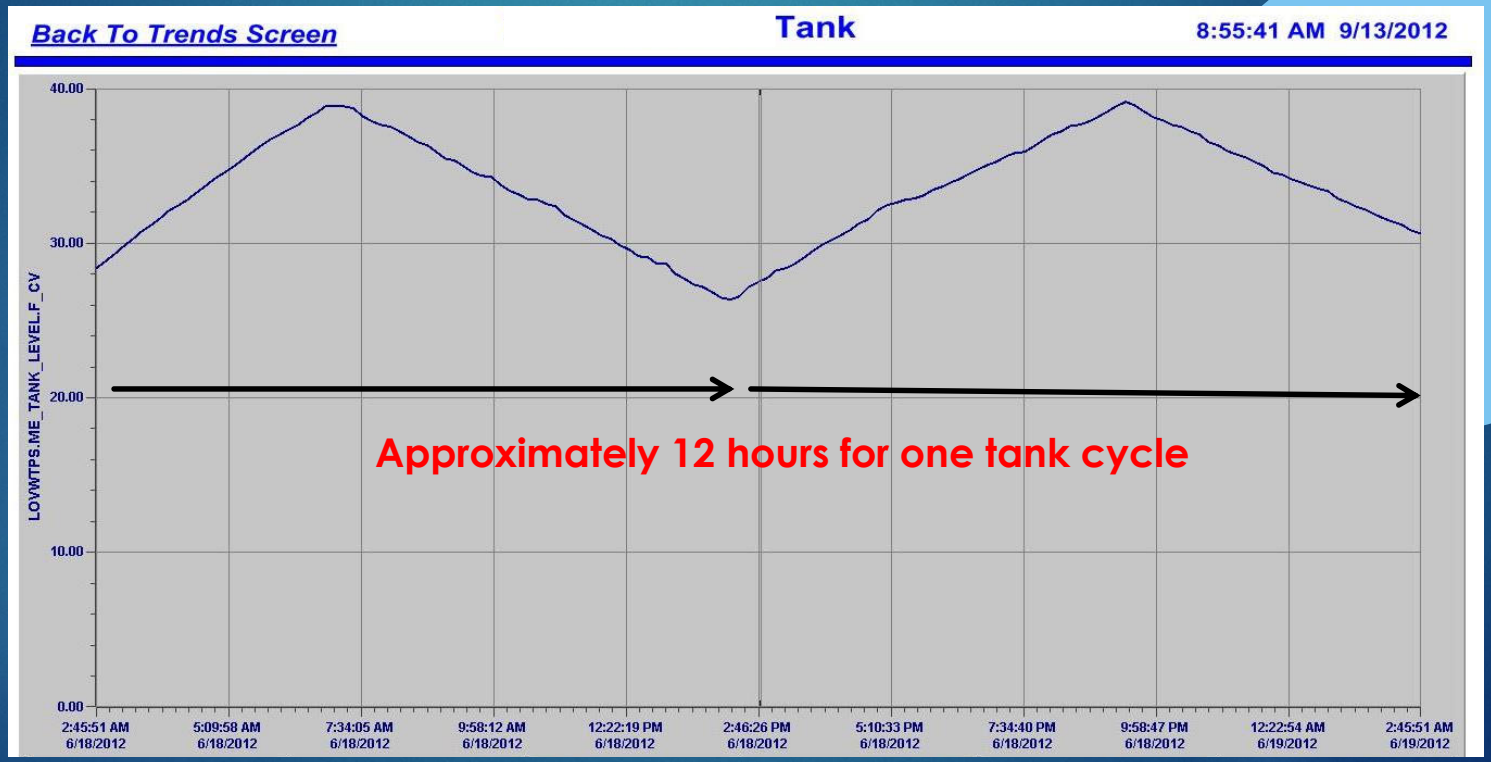
A large local industrial user obtains its water through a booster station that feeds a long transmission line to the industrial site.

Normal operation was for one pump to run all the time and a second one to come on a fill the storage tank when it reached its minimum allowed operating depth

One Pump Constantly Running and One To Fill The Tank

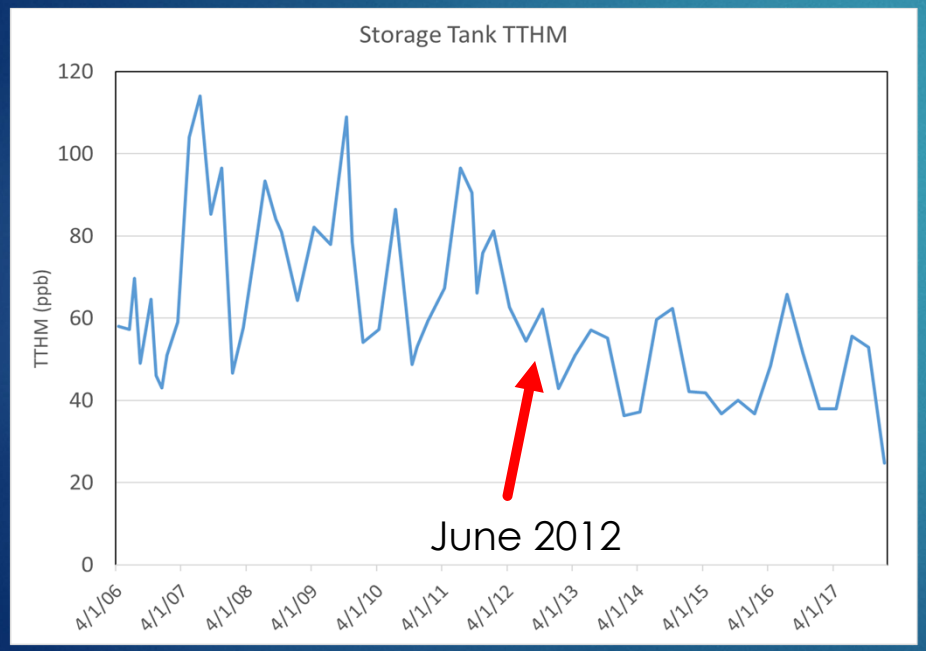


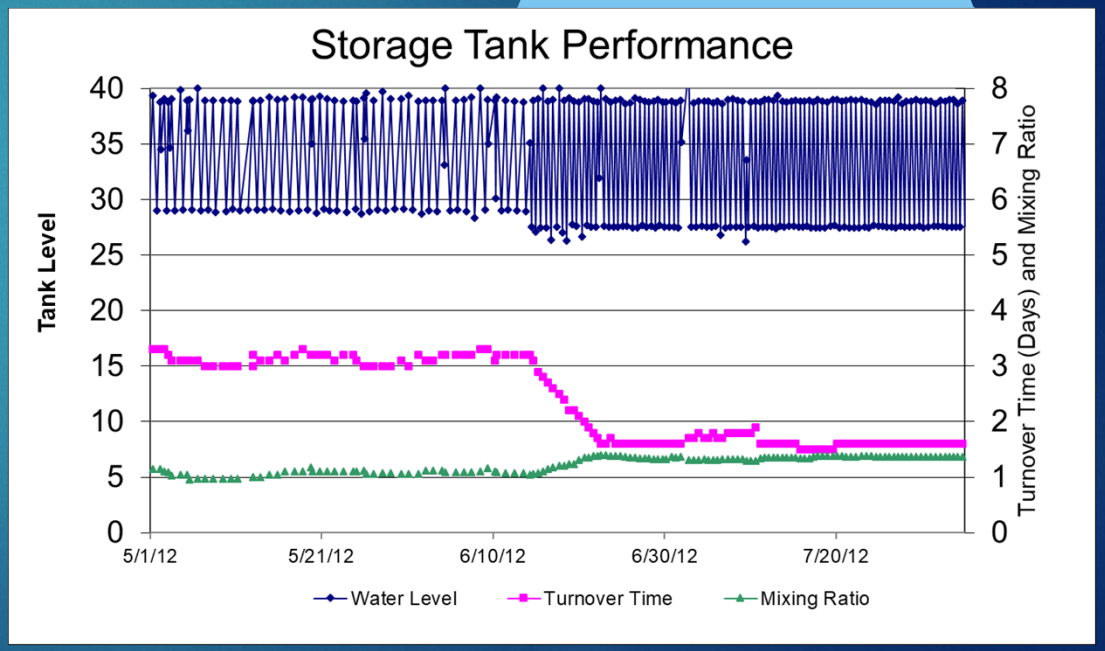
No Pumps On All The Time, Two Running In Tandem (SCADA Delay Between Starts)



Operational Changes Effect

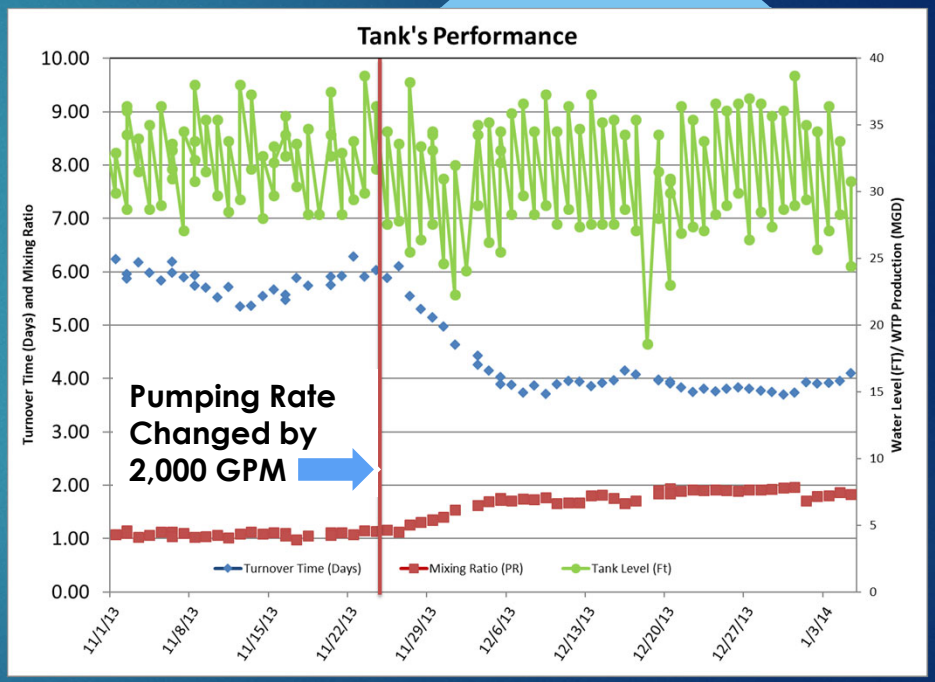
The pump station operation change was made in June 2012. Additionally, the water system was able to obtain authorization (very political) to lower the minimum level on the tank by 3 feet.





Water Treatment Pumping Change

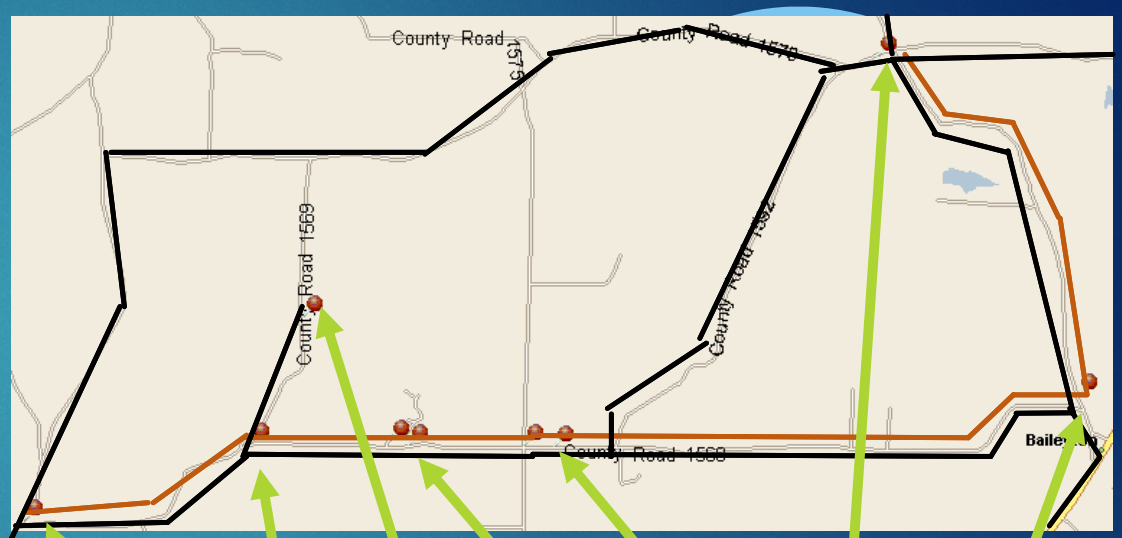
- Tank is feed directly from WTP.
- 2 MG Elevated
- Initial Performance
  - Initial Turnover Time > 8 days
  - Mixing Ration < 1.0
- Last change was to increase pumping to distribution by 2,000 GPM
  - Turnover decreased by 2 days
  - Mixing ration increase to almost 2.0
- Pumping faster allowed more time for distribution to drain.



Rerouting Water

Parallel Water Mains

- A water system outgrew the capacity of a 3-inch water main.
- Installed new 6-inch on other side of road.
- Did not abandon 3-inch water main to save money on not transferring customers to 6-inch (no service line road bores).
- Made connections between 3-inch and 6-inch at intersections for redundancy.

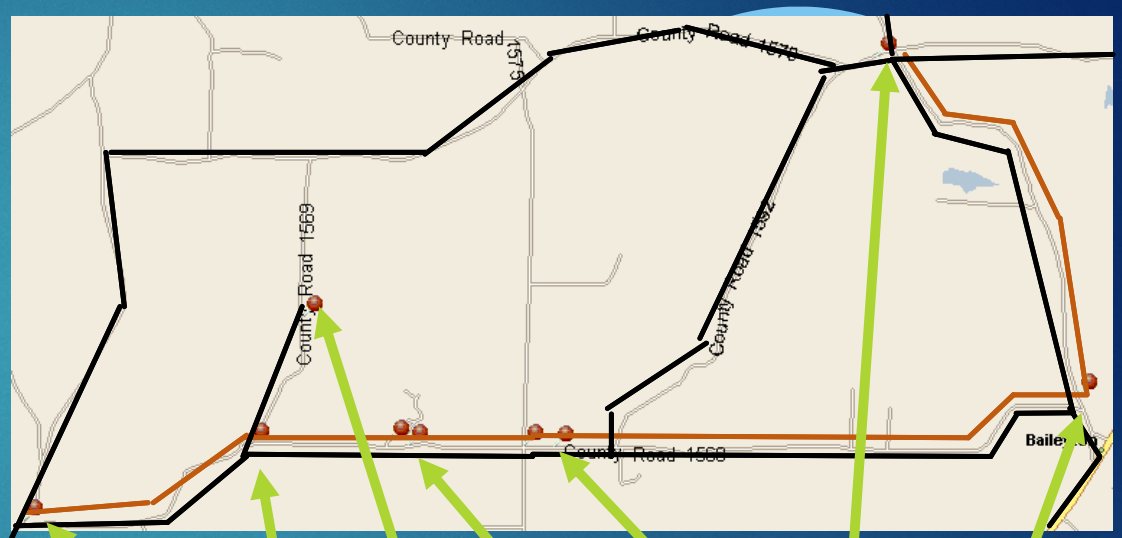


0.02 0.03 0.00 0.05 1.43 0.00 1.36

6-inch Initial CL2 Residuals

Parallel Water Mains

- Two options exist for improving water quality
  - Abandon 3-inch water main and transfer customers (costly).
  - Close valves at intersections and force water down 6-inch to feed 3-inch from other end.
- Second option was chosen and implemented. Chlorine residuals improved significantly.



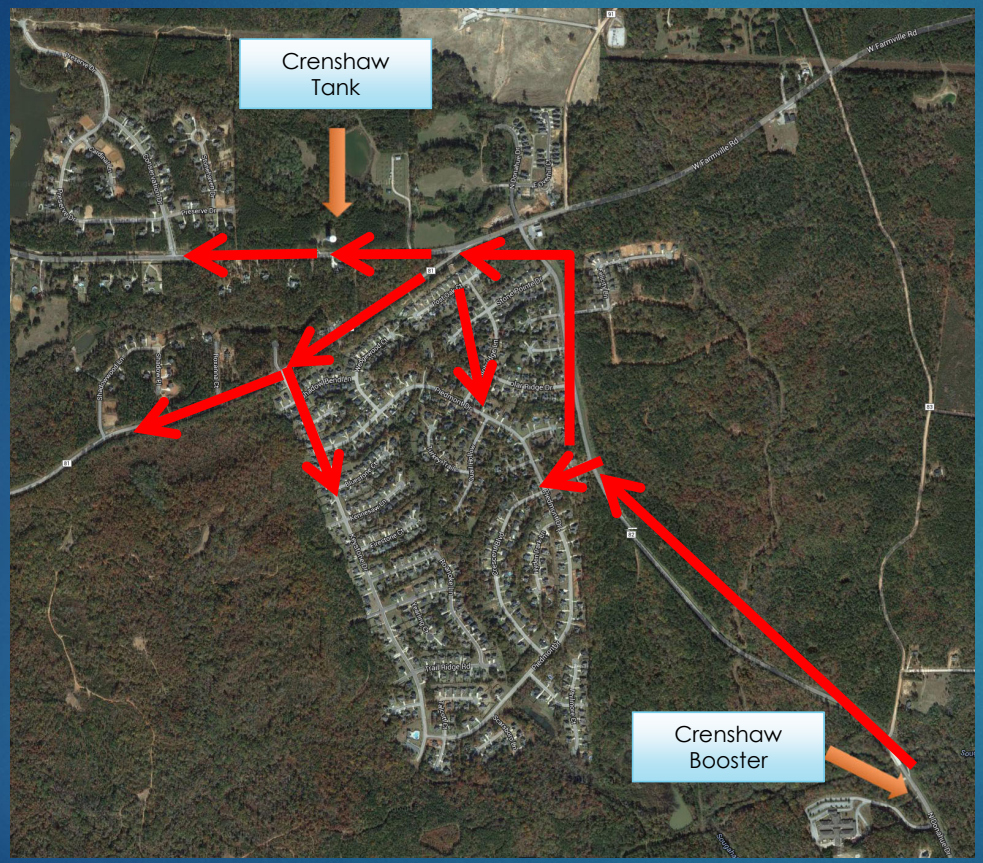
1.07 1.07 1.05 0.86 1.26 1.15 0.77

6-inch CL2 residuals after change

Using Industrial/Commercial Customers

- Consider putting industrial/commercial customers last instead of first.
- A county water system was able to close valves to reroute water through their low demand areas before supplying an industrial customer.
- Can be easily undone if need arises (repairs/ect).
- Chlorine residual in low demand areas improved as water was pulled through those areas to supply the industrial customer instead of supplying the industrial customer first.

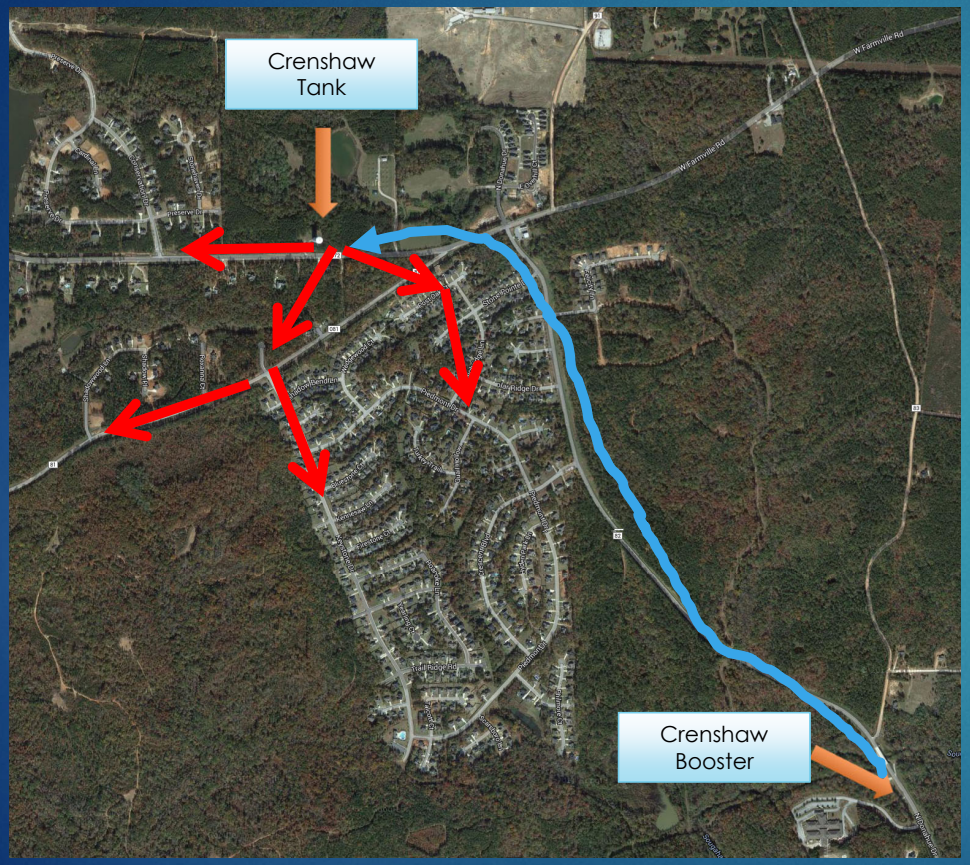
Crenshaw Tank – Old Flow Pattern



This area experienced low chlorine residuals (< 0.2 mg/L) in the area served by the storage tank.

Water personnel identified the storage tank as the issue, but the solution was not to alter the tank, but instead alter the distribution system.

Crenshaw Tank – New Flow Pattern



Water system personnel closed several valves to a subdivision which forced water to the storage tank before going to the distribution system.

This resulted in better turnover time, mixing and improved distribution chlorine residuals.

Additionally, the water system is altering the operational levels of the storage tank depending on the time of year.

The Unexpected

Stratification

- One water system thermally stratified a 10-inch water main by flushing at too low of a velocity
  - Water main is used to connect to a nearby water system for emergencies. Normal usage is low.
  - Auto-flusher installed to run at 20 gpm.
    - Improved chlorine residuals
    - Temperature 5-10 C above rest of water system
  - Opened fire hydrant and chlorine immediately went to zero
  - Installed new auto-flusher capable of 200 gpm.
    - Improved chlorine residuals
    - Temperature inline with rest of system

Thermal Degradation

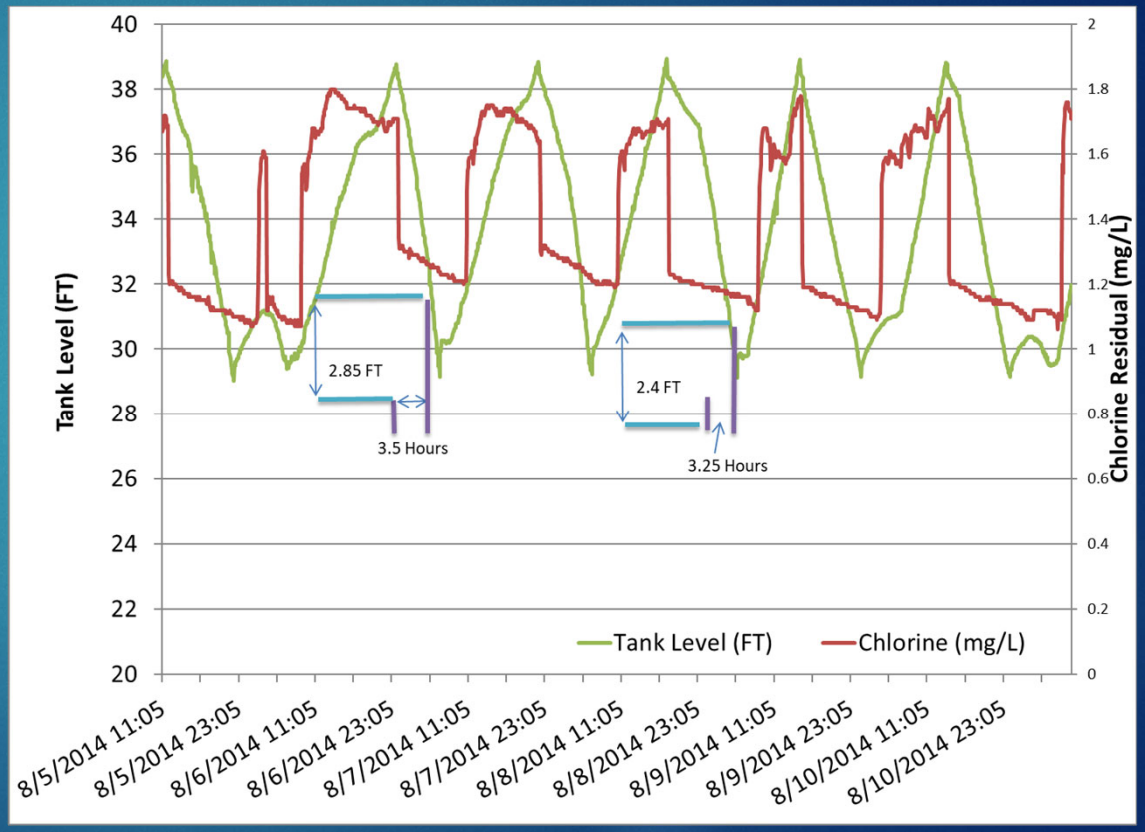
- Temperature plays a vital role in the maintenance of a chlorine residual.
- ± 5°C can have a significant impact on DBP formation.
- Several systems have found elevated temperatures >5°C difference in their distribution systems.
- The main culprit is shallow (< 2 ft) water mains. The water absorbs the heat being radiated into the ground from the asphalt.

Recycling Water

- How much water gets put back into a tank during a fill cycle?
- Analysis of one tank revealed the answer for that tank.
- Tank information
  - 1.5 MGD Elevated Storage
  - 97 Ft Diameter
  - 3.8 Day turnover, 1.2 mixing ratio

Recycling Water

- Using a continuous chlorine analyzer and tank level data
  - approximately 140,000 gallons were returned to the tank during each fill cycle.
  - Took approximately 3.25 hours to push old water back into tank.



Thank You!

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Effects of Storage Tanks on Water Quality: Part I

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Why are Storage Tanks Important?

- Tanks play an important role in DS operations, but can contribute to the degradation of water quality.
- Understanding how tanks impact water quality can help prioritize optimization efforts.
  - Design changes – tank mixer, aeration, booster disinfection
  - Operational changes – modify fill/draw cycles, pumping rates
  - Maintenance – cleaning, replacing coatings, repairing screens
- Tanks are often the main contributor to water age in a DS.

↑ Water Age ↓ Disinfectant Residual ↑ DBPs

Outline

- Storage Tank Overview
- Design, Operation, and Maintenance Factors that Impact Storage Tank Water Quality
- Assessing Storage Tank Water Quality
- Summary

Storage Tank Overview

Various Functions of Storage Tanks

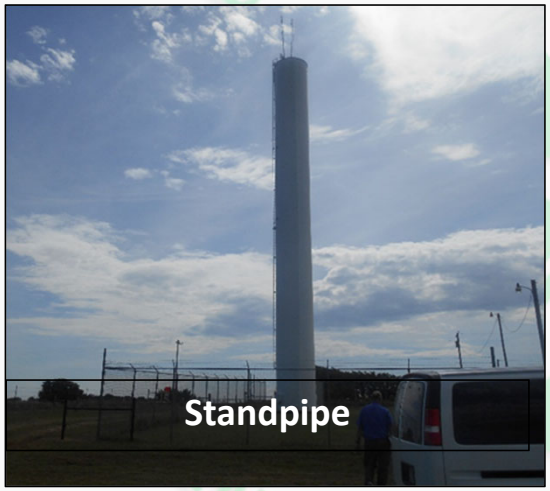
- Primary function is to equalize water supply, so pumping does not have to equal demand
- Secondary functions:
  - Pressure maintenance
  - Fire storage
  - Emergency storage
  - Reduce energy cost
  - Hydraulic transient control

Physical Characteristics

- Storage tanks can vary by the following:
  - **Size** – diameter (*d*), height (*h*), volume
  - **Shape** – cylindrical ($d \geq h$), standpipe ($d < h$), rectangular, ellipsoidal, pedestal, etc.
  - **Elevation** – underground, ground, elevated
  - **Inlet/Outlet** – configuration (common or separate), diameter, location
  - **Other** – baffling, pillars, mixing systems, treatment
- A tank's physical characteristics will impact water quality!

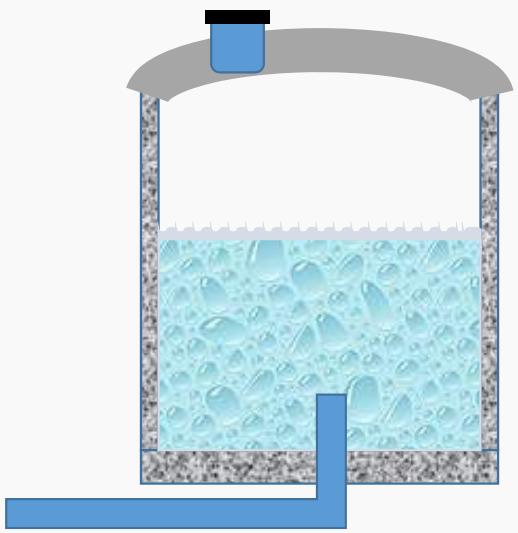
What Types of Tanks Do You See in Your State?


Ellipsoidal Elevated Tank

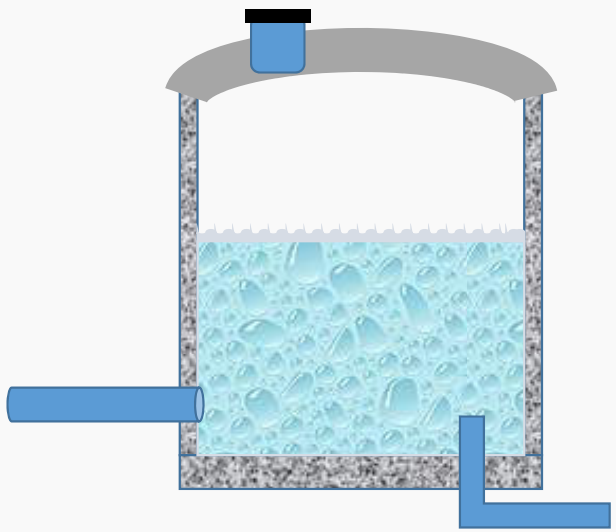

Standpipe


Cylindrical Ground Tanks

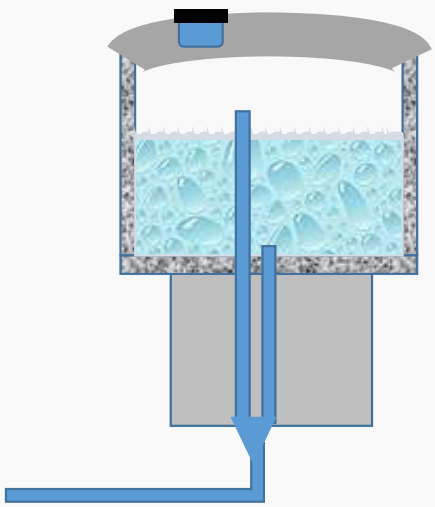
Various Types of Inlet/Outlet Configurations



Common Inlet/Outlet



Separate Inlet/Outlet



Separate Inlet/Outlet with Common Feed Line

Modified: Courtesy of Jeff Swertfeger
Greater Cincinnati Water Works

Storage Tank Turnover Time

- Turnover time (or water age) is the average amount of time that water is in a tank.
- Unless completely mixed, the water age in different sections of a tank will vary.
- Turnover time is a function of tank design and operations.
- All tanks should be assessed on a routine basis.

Storage Tank Mixing

- Process of making a heterogeneous (e.g., plug-flow) system homogenous (e.g., CSTR)
  - Clearwells are often designed to operate as plug-flow to maximize residence time.
  - Storage tanks in the DS are often designed to be fully mixed to minimize average water age.
- Mixing is a function of tank design and operations.

AWOP Storage Tank Operational Guidelines

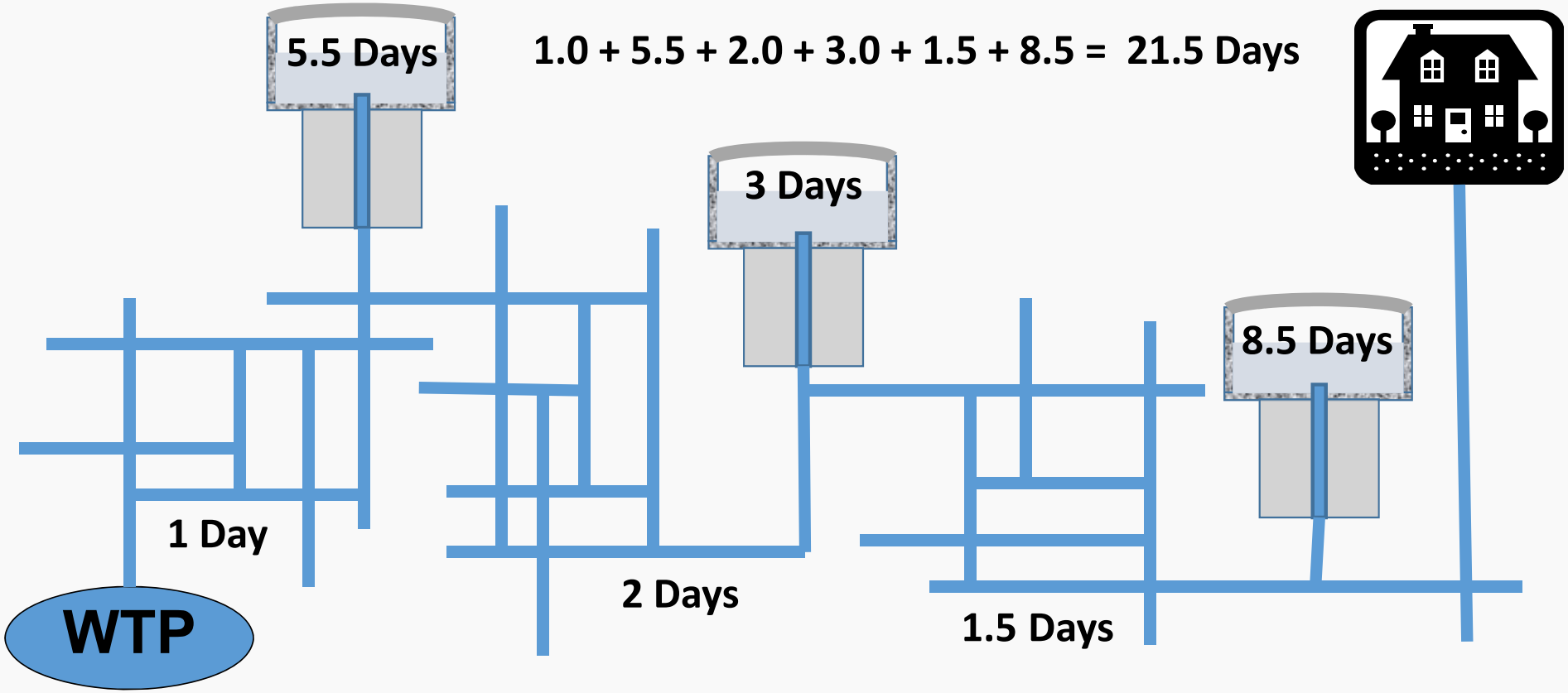
- **Turnover Time:** Maintain average water age < 5 days *or* maintain an established turnover rate at each individual storage facility
- **Mixing:** Maintain good mixing at all times
  - Estimate tank mixing using tank spreadsheet (P.R. ≥ 1.0), if mixing calculations apply
  - Verify by in-tank water quality sampling, temperature monitoring, or other means

Design, Operation, Maintenance, and Environmental Factors that Impact Storage Tank Water Quality

Design and Operational Factors that Impact Turnover Time

- Design Factors:
  - Volume
  - Elevation
  - Location in system
- Operational Factors:
  - Tank level operating range
    - Minimum emergency storage capacity
    - Minimum pressure requirements
  - Pumping schedules (i.e., duration, frequency, rate)

Cumulative Water Age of Tanks in Series



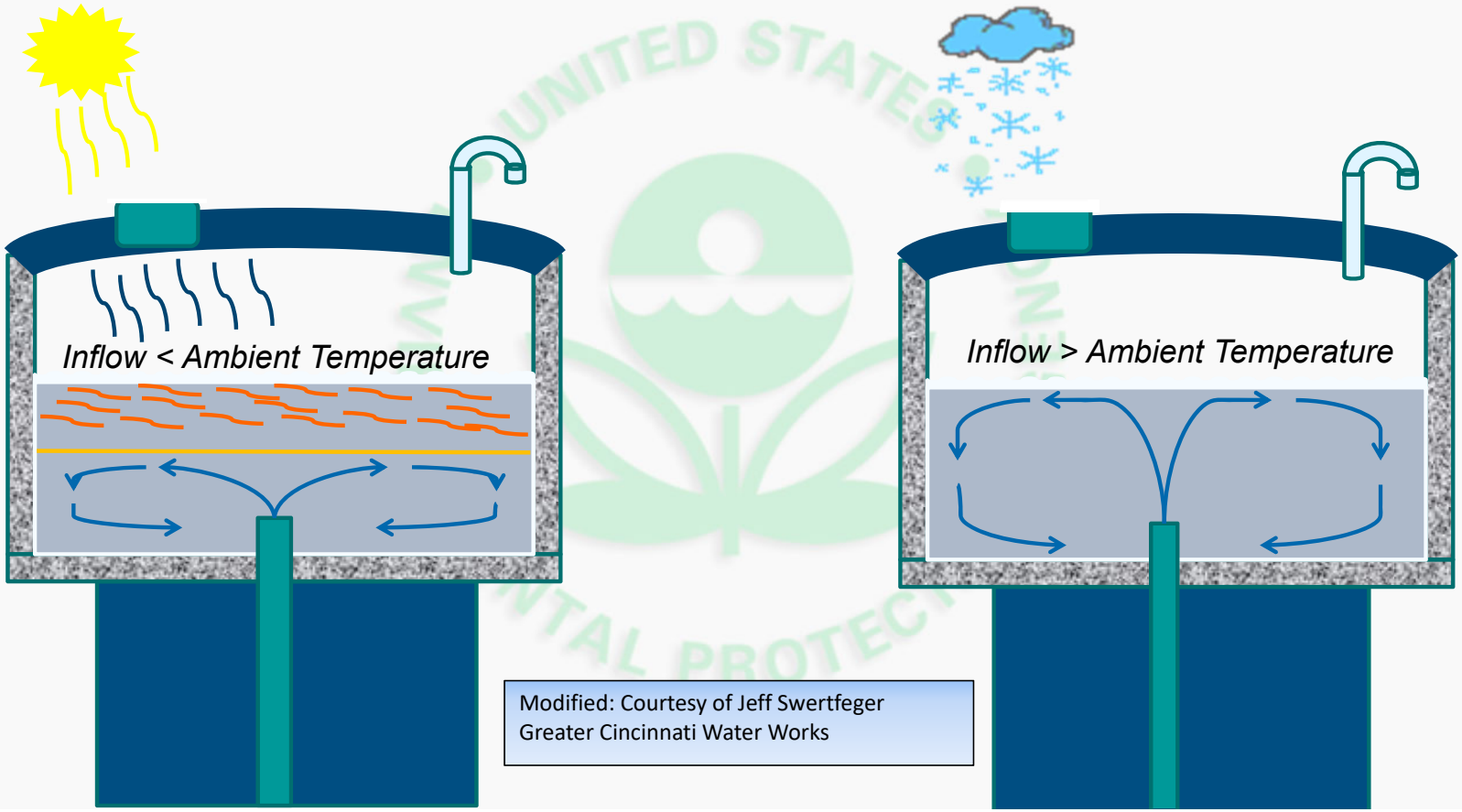
Potential Strategies to Reduce Turnover Time

- Operational:
  - Reduce water volume in tank by operating at lower levels
  - Increase demand on tank by closing valves to modify system hydraulics
- Design:
  - Reduce overall volume in the DS
    - Remove tank(s) from service
    - Reduce line size (i.e., diameter)

Design, Operational, and Environmental Factors that Impact Mixing

- Design Factors:
  - Tank shape – standpipe, cylindrical, rectangular, ellipsoidal, other
  - Tank size – diameter, height, volume
  - Inlet/outlet (I/O) – configuration, diameter, location, orientation
  - Engineering controls – baffling and mixers (passive and mechanical)
- Operational Factors:
  - Inlet flow – fill velocity and fill cycle duration
- Temperature Differentials:
  - Inflow > Ambient – Promotes Mixing
  - Inflow < Ambient – Impedes Mixing

Temperature Impacts on Tank Mixing



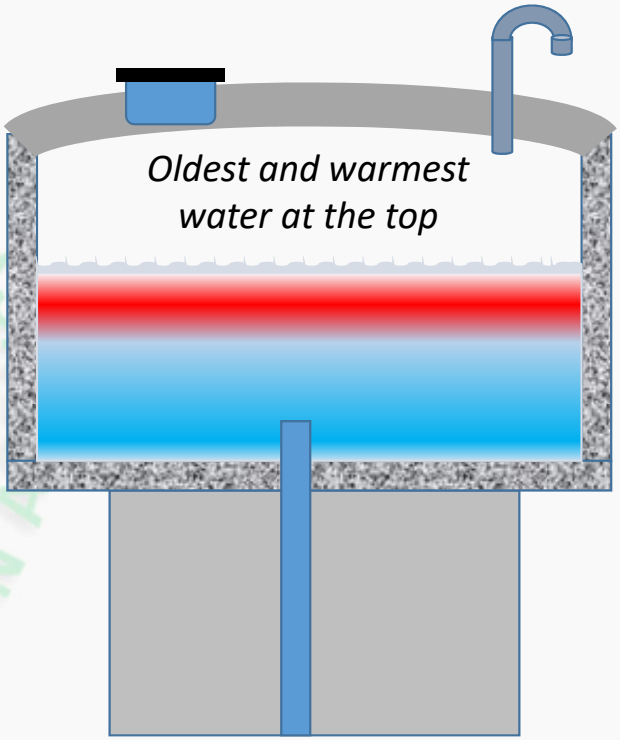
Modified: Courtesy of Jeff Swertfeger
Greater Cincinnati Water Works

Potential Strategies to Improve Mixing

- Operational:
  - Increase operating span to increase fill duration (mixing time)
  - Modify pumping rates to optimize fill velocity and duration
    - Higher fill velocity over a shorter duration
    - Lower fill velocity over a longer duration
- Design:
  - Install an engineered mixing system (passive or active)
  - Decrease inlet diameter to increase inlet velocity

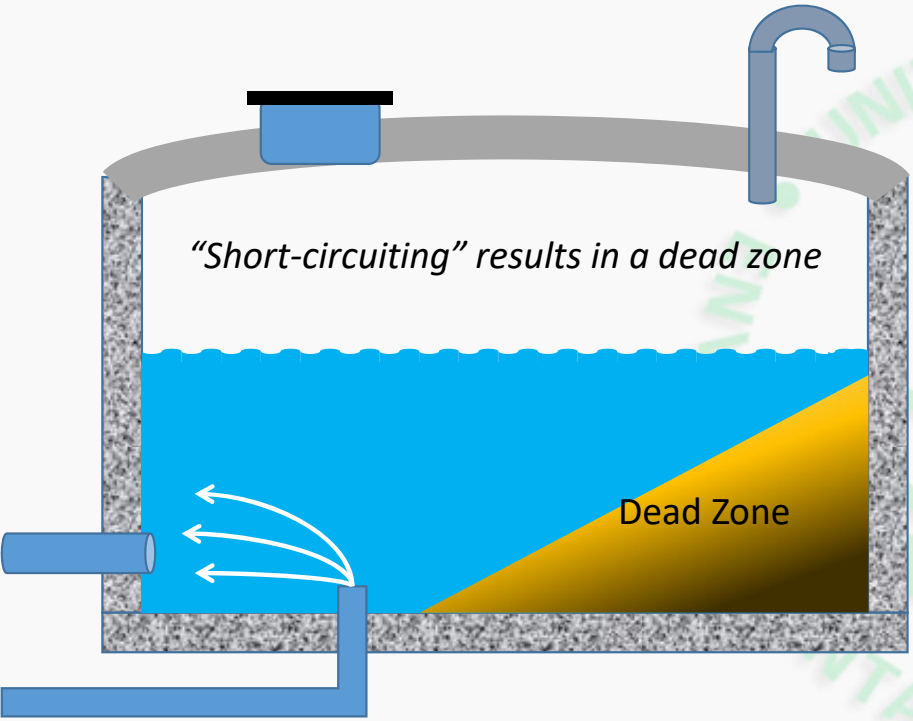
Turnover Time and Mixing Impact Water Quality

- Example #1:
  - Average water age of 14 days
  - Common I/O configuration
  - Thermally stratified
  - No mixing device installed
- Poor quality water may accumulate within tank under normal operations
- May have more limited impact on thermally stratified system with common I/O



Modified: Courtesy of Jeff Swertfeger
Greater Cincinnati Water Works

Turnover Time and Mixing Impact Water Quality



Modified: Courtesy of Jeff Swertfeger
Greater Cincinnati Water Works

- Example #2
  - Average water age of 2.5 days
  - Separate I/O located in close proximity
  - Poorly mixed
- Proximity of inlet and outlet results in poor mixing
- Installing a mixer may improve water quality

Maintenance Factors that Impact Water Quality

Activity	Potential Area of Water Quality Improvement
Remove Sediment	Taste and odor, reduce disinfectant demand, reduce DBP formation, and corrosion
Repair and/or Replace Coatings	Taste and odor, disinfectant demand, DBP formation, and corrosion
Repair and/or Replace Screens and Hatches	Taste and odor, disinfectant demand, DBP formation, and corrosion
Provide Additional Curing for New Coatings	Taste and odor
Repair Cathodic Protection	Corrosion

Source: AWWA RF Report: Maintaining Water Quality in Finished Storage Facilities, 1999

Effects of Storage Tanks on Water Quality: Part 2

Paul Handke

Pennsylvania Department of Environmental Protection; Bureau of Safe Drinking Water

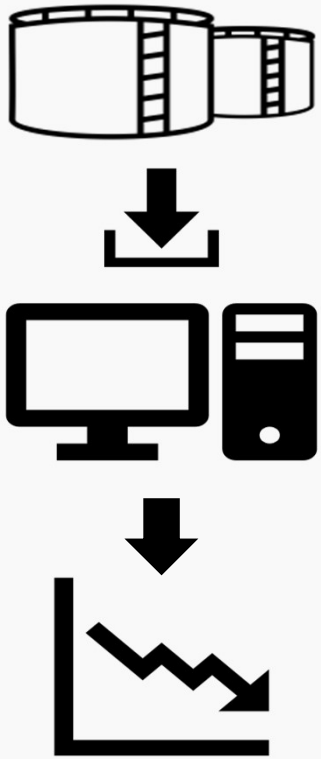
Division of Training, Technical, and Financial Services

Assessing Storage Tank Water Quality

- Storage Tank Assessment Spreadsheet
- Water Quality Monitoring
  - Investigative Sampling
  - Continuous Online Monitoring
  - In-Tank Monitoring

Storage Tank Assessment Spreadsheet

- Estimates average tank turnover time and mixing performance using:
- Physical Characteristics – volume, shape, dimensions, I/O diameter and configuration
- Operational Data – minimum and maximum tank level data over a period of time (e.g., SCADA)
- Does not directly assess water quality



Storage Tank Assessment Spreadsheet

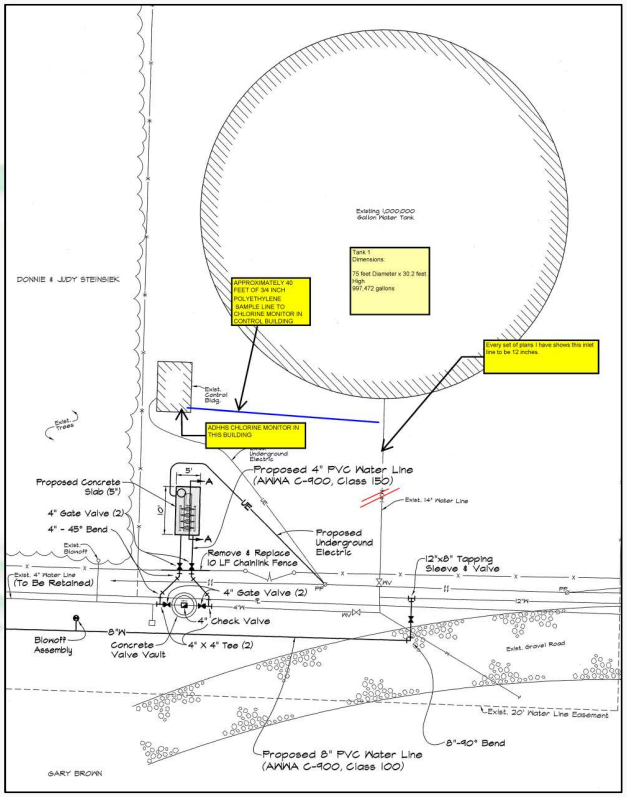
- Spreadsheet consists of four main components:
  - *Instructions* – general guidelines, applications, and limitations
  - *Summary* – input physical characteristics of tank(s)
  - *Tank Worksheet(s):*
    - Input: operational data of tank(s) – develops graphical summary
    - Output: average turnover time and mixing performance ratio
    - Advanced: potential operational strategies can be evaluated
  - *Glossary* – definitions of terms associated with tanks

Determine Spreadsheet Applicability

- Consider spreadsheet limitations before use.
- Turnover and mixing estimates only apply to tanks with:
  - Common I/O configuration
  - Known volume vs. depth relationship
- Additionally, mixing estimates only apply to tanks:
  - Not thermally stratified
  - Not containing baffling, pillars, or mixing devices
- *Instructions* worksheet specifies these applications and limitations.

Identify Physical Characteristics of Tank(s)

- Inputs include:
  - Volume (MG)
  - Shape – cylindrical, rectangular, and hydropillar
  - Tank diameter (ft) or sidewall lengths (ft)
  - I/O diameter (ft)
  - I/O configuration – “fill-draw” or “flow-through”
  - Maximum operating depth (ft)
- Engineering drawings may be needed, which can be difficult to obtain.



Enter Physical Characteristics into Summary Worksheet

Tank Summary

Instructions:
1. Enter tank design data for each tank into *Section I* of the *Tank Summary* worksheet (user input is shown in red). *Section II* of the *Tank Summary* worksheet will be populated after data is entered into *Section I* and the respective *Tank* worksheet.
2. Enter the tank level data into *Section I* of the *Tank* worksheet(s).
3. If the estimated turnover time and/or mixing is poor, *Sections 2 and/or 3* of the *Tank* worksheet will evaluate potential operational strategies and/or design strategies to improve tank performance.

User Inputs Tank Characteristics

Section I. Physical Characteristics (See *Glossary* worksheet for details)

		Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank #9
Name of Tank	Example									
Volume (MG)	0.5									
Is the tank Cylindrical (C), Rectangular (R), Hydropillar (H), or None of these (n)?	r									
Is tank level data in volume (y/n)?	n									
Are tank mixing equations applicable based on the *Introduction* worksheet (y/n)?	y									
Tank diameter (if cylindrical/hydropillar) or longest sidewall length (if rectangular)(ft)	50									
Shortest sidewall length (If rectangular) (ft)	30									
Inlet Diameter (ft)	1.00									
Maximum Operating Water Depth (ft)	24									
Is the tank operated fill-draw (fd) or flow-through[2] (ft)?	fd									
H/D ratio	0.48	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Section II. Tank Calculations (from *Tank* worksheets)

****If turnover time and/or mixing estimations do not apply this section may be blank.**

Spreadsheet Output

Average Turnover Time (days)	4.6									
Mixing Performance Ratio (Measured/ Desired)	0.37									

Notes:
1. Hydropillar tanks can be approximated as cylindrical tanks depending on their operating range. See *Glossary* worksheet for illustration.
2. In flow-through operation water is simultaneously coming into the tank and leaving the tank. In fill-draw operation water can either be filling the tank or drawing from the tank at anytime (this is most common).

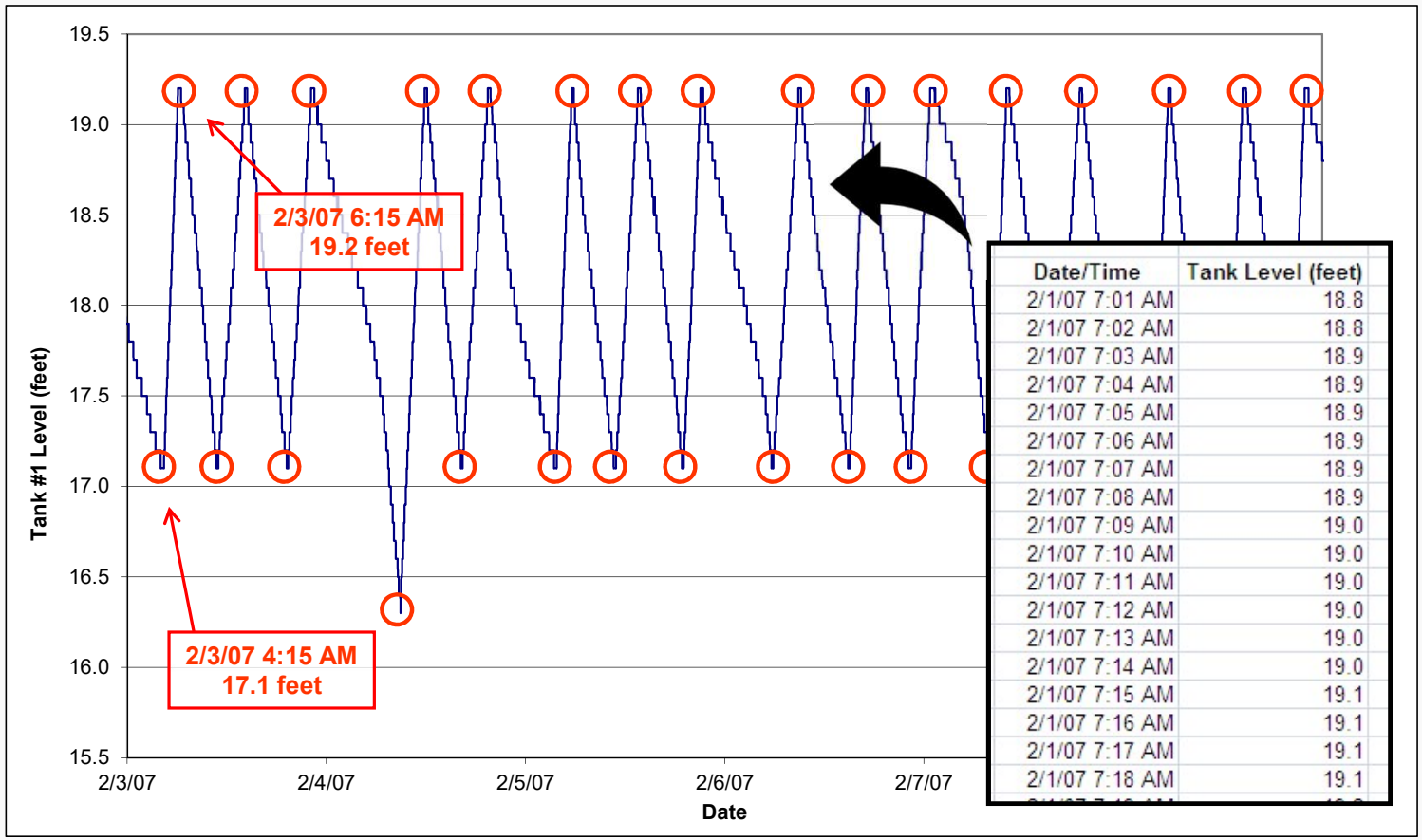
- Enter physical characteristics into the *Summary* worksheet.
- Verify units of input data

Collect Tank Level Operational Data

- SCADA, data loggers, chart recorders, or pressure recorders are sources of *tank level data*.
  - One to two week period (15 fill/draw cycles)
  - Evaluate typical operations (i.e., not during major line breaks or fires)

Date/Time	Tank Level (feet)
2/1/07 7:01 AM	18.8
2/1/07 7:02 AM	18.8
2/1/07 7:03 AM	18.9
2/1/07 7:04 AM	18.9
2/1/07 7:05 AM	18.9
2/1/07 7:06 AM	18.9
2/1/07 7:07 AM	18.9
2/1/07 7:08 AM	18.9
2/1/07 7:09 AM	19.0
2/1/07 7:10 AM	19.0
2/1/07 7:11 AM	19.0
2/1/07 7:12 AM	19.0
2/1/07 7:13 AM	19.0
2/1/07 7:14 AM	19.0
2/1/07 7:15 AM	19.1
2/1/07 7:16 AM	19.1
2/1/07 7:17 AM	19.1
2/1/07 7:18 AM	19.1

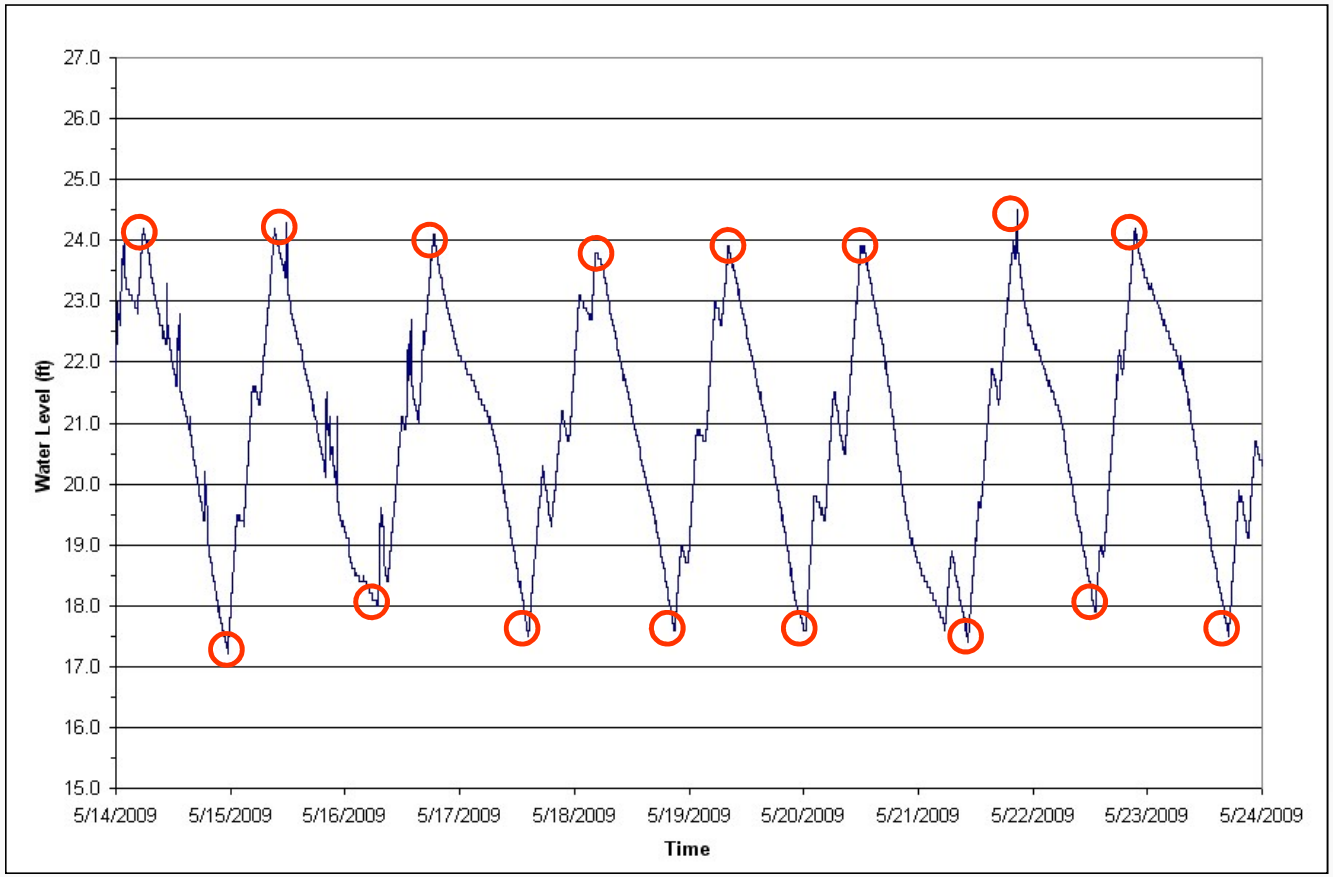
Interpreting Tank Level Operational Data



Date/Time	Tank Level (feet)
2/1/07 7:01 AM	18.8
2/1/07 7:02 AM	18.8
2/1/07 7:03 AM	18.9
2/1/07 7:04 AM	18.9
2/1/07 7:05 AM	18.9
2/1/07 7:06 AM	18.9
2/1/07 7:07 AM	18.9
2/1/07 7:08 AM	18.9
2/1/07 7:09 AM	19.0
2/1/07 7:10 AM	19.0
2/1/07 7:11 AM	19.0
2/1/07 7:12 AM	19.0
2/1/07 7:13 AM	19.0
2/1/07 7:14 AM	19.0
2/1/07 7:15 AM	19.1
2/1/07 7:16 AM	19.1
2/1/07 7:17 AM	19.1
2/1/07 7:18 AM	19.1

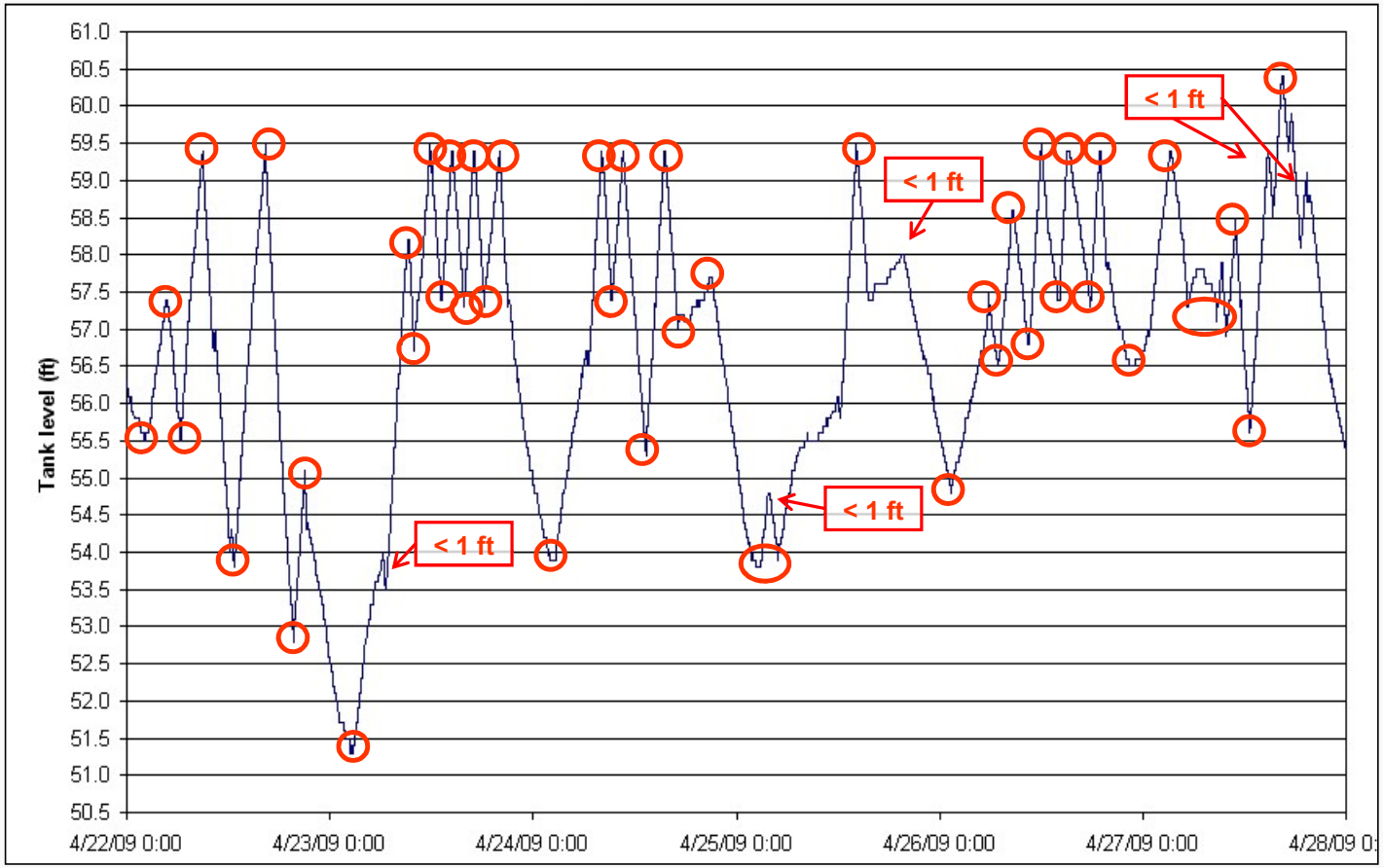
- Interpret minimum and maximum tank levels with corresponding time and date.
- Consider plotting tabular tank level data for visual interpretation.

Tank Level Data Interpretation – Example A



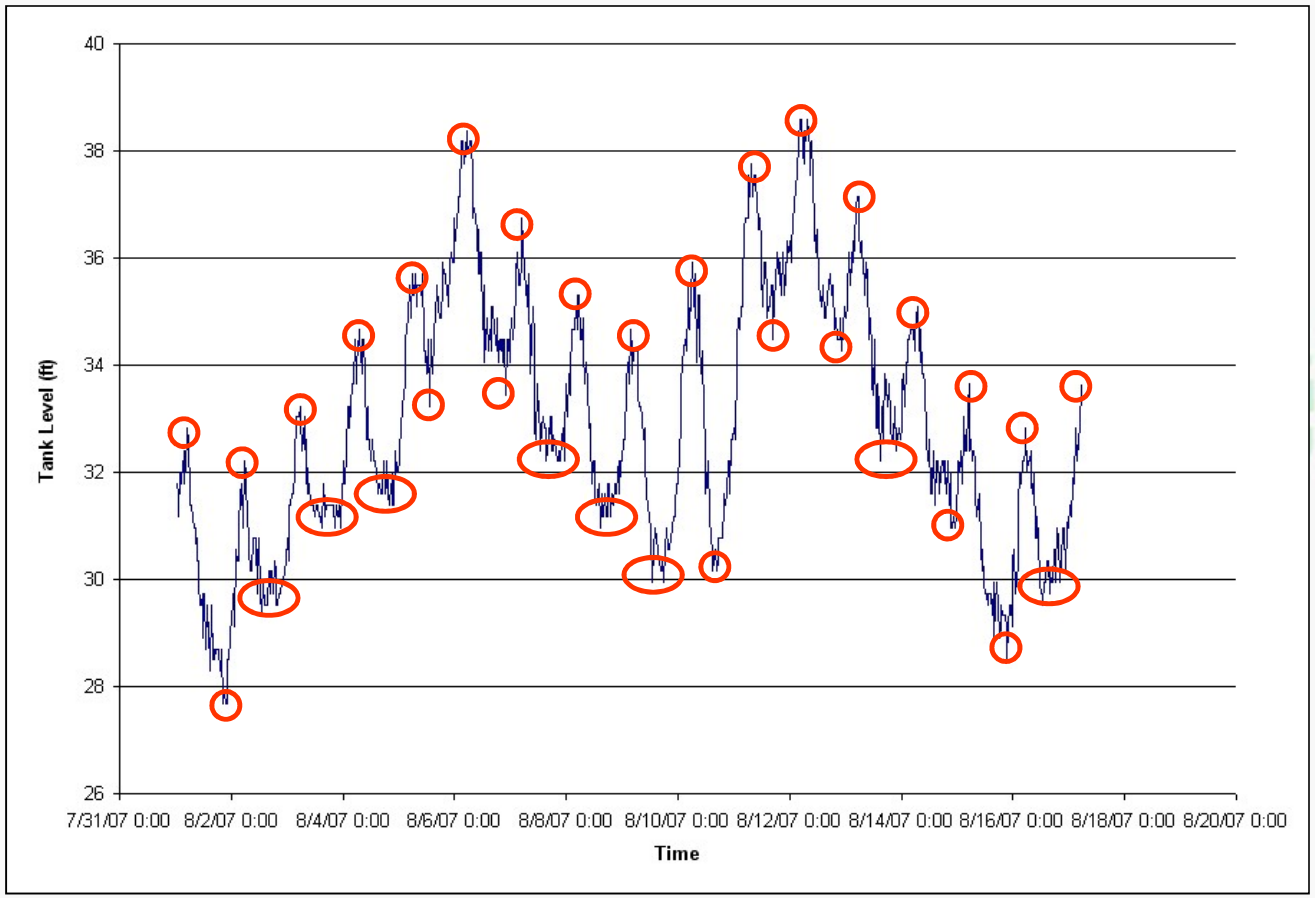
- Minimum and maximum tank operational setpoints are clear.
- Minor variations in tank level data are observed.

Tank Level Data Interpretation – Example B



- Minimum and maximum tank operational setpoints are not clear.
- Identify tank cycles to be ≥ 1 ft level change.

Tank Level Data Interpretation – Example C



- Minimum and maximum tank operational setpoints are not clear.
- Identifying tank cycles ≤ 1 ft is not practical.
- Define a practical level change.
- Generalize erratic tank operations.

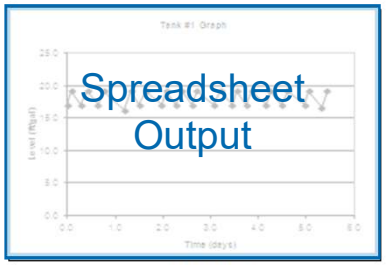
Enter Tank Level Data into *Tank* Worksheet(s)

Tank #1 Worksheet

Step 1: Data Input- Tank Turnover and Mixing Calculations

Tank Name:	TANK ONE
Volume, MG:	1
Cylindrical (C), Rectangular (R), Hyperbolic (H), or Manual (M):	C
If none, do not SCADA report volume (or % full after this):	0.00
Maximum Water Depth, H:	30 ft
Tank diameter, D:	75 ft
	0
H/D ratio:	0.40
Inlet diameter, d:	1.00 ft

Spreadsheet Output



Spreadsheet Output

Instructions: Enter tank fill data (obtained from plant SCADA) for up to 15 fill periods. Data inputted by the user are shown in red.

Date	Time	Min Level Ft	Max Level Ft	Date + Time	Delta Time Days	Level Change Ft
02/03/07	4:15 AM	17.10		2/3/07 4:15	0.0	17.1
02/03/07	6:15 AM		19.20	2/3/07 6:15	0.08	19.2
02/03/07	10:50 AM	17.10		2/3/07 10:50	0.27	17.1
02/03/07	2:20 PM		19.20	2/3/07 14:20	0.42	19.2
02/03/07	7:20 PM	17.10		2/3/07 19:20	0.63	17.1
02/03/07	10:20 PM		19.20	2/3/07 22:20	0.75	19.2
02/04/07	8:55 AM	16.30		2/4/07 8:55	1.19	16.3
02/04/07	12:00 PM		19.20	2/4/07 12:00	1.32	19.2
02/04/07	4:20 PM	17.10		2/4/07 16:20	1.50	17.1
02/04/07	7:40 PM		19.20	2/4/07 19:40	1.64	19.2
02/05/07	3:35 AM	17.10		2/5/07 3:35	1.97	17.1
02/05/07	5:40 AM		19.20	2/5/07 5:40	2.08	19.2
02/05/07	10:45 AM	17.10		2/5/07 10:45	[illegible]	17.1
02/05/07	1:45 PM		19.20	2/5/07 13:45	[illegible]	19.2
02/05/07	6:55 PM	17.10		2/5/07 18:55	2.61	17.1
02/05/07	[illegible]		19.20	2/5/07 21:15	[illegible]	19.2
02/06/07	5:45 AM	17.10		2/6/07 5:45	3.05	17.1
02/06/07	9:00 AM		19.20	2/6/07 9:00	3.20	19.2
02/06/07	3:00 PM	17.10		2/6/07 15:00	3.45	17.1
02/06/07	5:10 PM		19.20	2/6/07 17:10	3.54	19.2
02/06/07	10:15 PM	17.10		2/6/07 22:15	3.75	17.1
02/07/07	1:00 AM		19.20	2/7/07 1:00	3.86	19.2
02/07/07	7:55 AM	17.10		2/7/07 7:55	4.15	17.1
02/07/07	10:10 AM		19.20	2/7/07 10:10	4.25	19.2
02/07/07	3:45 PM	17.10		2/7/07 15:45	4.48	17.1
02/07/07	6:55 PM		19.20	2/7/07 18:55	4.61	19.2
02/08/07	3:25 AM	17.10		2/8/07 3:25	4.97	17.1
02/08/07	5:35 AM		19.20	2/8/07 5:35	5.06	19.2
02/08/07	12:05 PM	16.70		2/8/07 12:05	5.33	16.7
02/08/07	2:35 PM		19.20	2/8/07 14:35	5.43	19.2

User Input

Spreadsheet Output

Review Tank Assessment Summary

Fill period	Low/Min Level (ft)	High/Max Level (ft)	Vol at start of fill cycle (MG)	Vol added during fill cycle (MG)	Volume drawn during drain cycle (MG)	Ave Tank Vol during fill cycle (MG)	Mixing calculations: Actual Volume Exchange Fraction (VEF)	Mixing calculations: Dimension-less Mixing Time	Mixing calculations: Req'd Volume Exchange Fraction (VEF)	Fill Time (days)	Draw Time (days)
1	17.10	19.20	0.57	0.07		0.60	0.12	10.20	0.21	0.08	n/a
2	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.15	0.19
3	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.13	0.21
4	16.30	19.20	0.54	0.10	0.10	0.59	0.18	10.20	0.22	0.13	0.44
5	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.14	0.18
6	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.09	0.33
7	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.13	0.21
8	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.10	0.22
9	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.14	0.35
10	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.09	0.25
11	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.11	0.21
12	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.09	0.29
13	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.13	0.23
14	17.10	19.20	0.57	0.07	0.07	0.60	0.12	10.20	0.21	0.09	0.35
15	16.70	19.20	0.55	0.08	0.08	0.59	0.15	10.20	0.22	0.10	0.27

Spreadsheet Output

Turnover Summary		
Avg Vol Added in One Fill Period	0.07	MG
Avg Vol Drawn in One Drain Period	0.07	MG
Avg Fill Time	0.11	days
Avg Draw Time	0.27	days
Avg Fill Rate	[illegible]	gpm
Avg Draw Rate	[illegible]	gpm
Avg Duration (Fill + Draw Time)	0.4	[illegible]
Avg Flow Rate into tank	0.19	MGD
Avg Tank Vol	0.60	MG
Turnover Time	3.2	days

Spreadsheet Output

3.2 days

Mixing Summary		
Avg Min Water Level	17.0	ft
Avg Actual VEF	[illegible]	
Avg VEF Needed for Good Mixing	0.21	
Avg Measured Water Vol Change	[illegible]	ft
Desired Water Level Change Needed for Good Mixing	3.6	[illegible]
Mixing Performance Ratio (Measured/Desired)	0.60	
Inlet Diameter Needed for Good Mixing	7	inches

Spreadsheet Output

0.60 Mixing Ratio

- Results located on bottom of *Tank* worksheet.
- Average water age ≤ 5 days is desired.
- Mixing P.R. ≥ 1.0 is desired.

Advanced Use: Assessing Impact of Operational and Design Changes

Section II: Turnover Time & Mixing Analysis

Instructions: Five scenarios are available for experimenting with changing tank operations to improve turnover time. Experiment with lowering the both the Max and Min levels, only the Min level, and only the Max level. Modify data shown in red. Do not use this analysis if the turnover time equations are not applicable!

These five scenarios are also available for experimenting with reducing inlet diameter to improve mixing. Note that improving the level change will also improve mixing. Modify data shown in red. Do not use this analysis if the mixing equations are not applicable (H/D>1)!

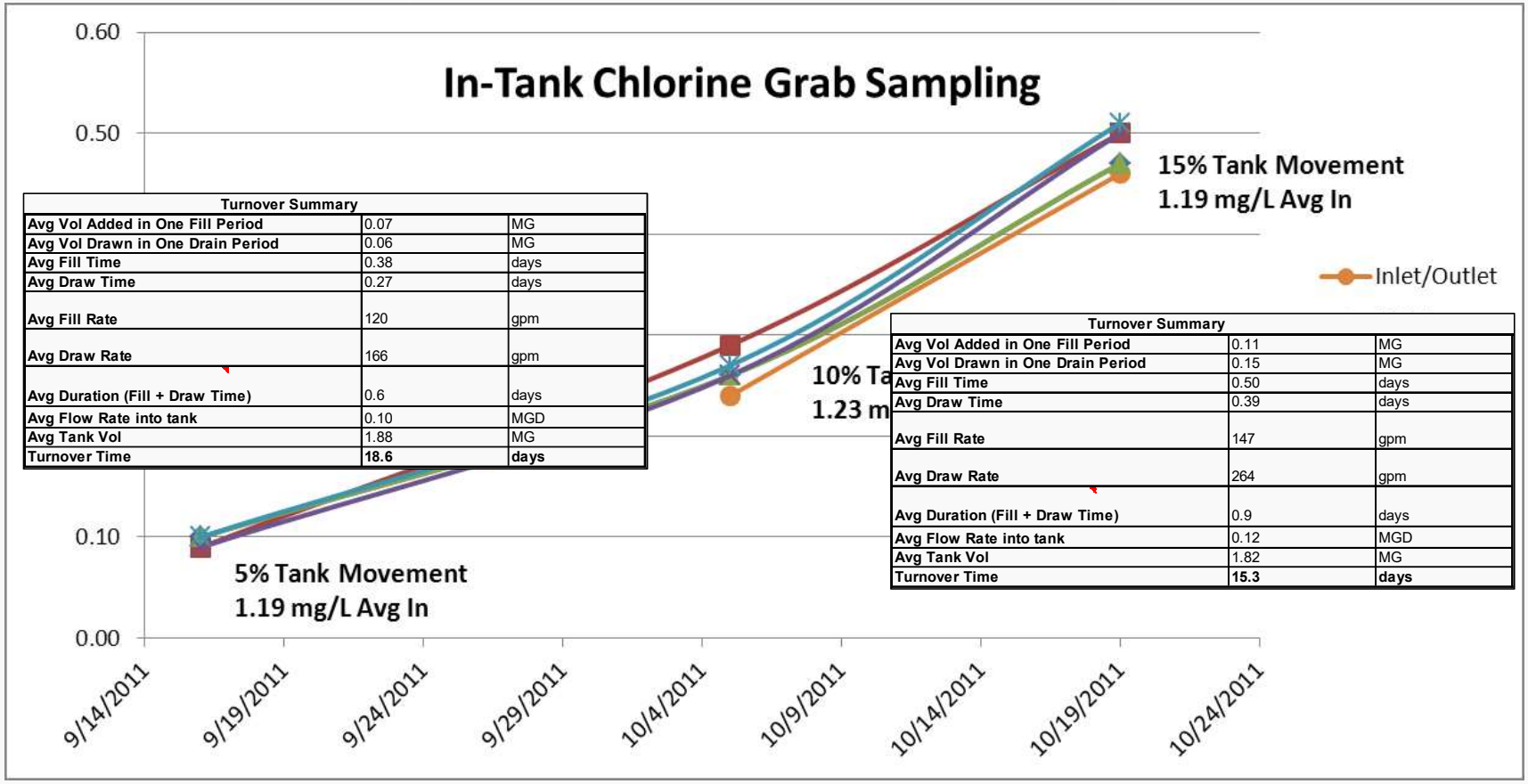
	No Changes	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	
Tank diameter	50	50	50	50	50	50	ft
	0	0	0	0	0	0	ft
Inlet Diameter	1.00	1.00	1.00	1.00	0.50	0.50	ft
High/Max Level	18.71	17.00	18.71	18.00	18.71	18.71	ft
Low/Min Level	16.79	15.00	15.00	16.79	16.79	15.00	ft
H/D ratio	0.37	0.34	0.37	0.36	0.37	0.37	
Actual Level Change	1.92	2.00	3.71	1.21	1.92	3.71	ft
Dimensionless Mixing Time	10.20	10.20	10.20	10.20	10.20	10.20	
Desired Level Change Needed for Good	4.73	4.38	4.38	4.73	2.36	2.19	ft
Pressure Drop After Change in Min Water Level		0.8	0.8	0.0	0.0	0.8	psi
Fill rate/ Pumping rate	71	71	71	71	71	71	gpm
Draw rate/ consumer demand	88	88	88	88	88	88	gpm
Avg fill time	0.27	0.29	0.53	0.17	0.27	0.53	days
Avg draw time	0.22	0.23	0.43	0.14	0.22	0.43	days
Avg volume added during fill	0.03	0.03	0.05	0.02	0.03	0.05	MG
Avg Duration (fill	0.50	0.52	0.96	0.31	0.49	0.96	days
Ave Flow Rate	0.06	0.06	0.06	0.06	0.06	0.06	MGD
Ave Tank Vol	0.26	0.24	0.25	0.26	0.26	0.25	MG
Mixing Performance Ratio	0.41	0.46	0.85	0.26	0.81	1.69	
Turnover Time	4.6	4.2	4.4	4.5	4.5	4.4	days

- Assess changes in minimum and maximum operating levels
- Assess changes in inlet diameter

Interpreting Tank Spreadsheet Results

- Turnover time analysis:
  - Estimation of *average* turnover time in tank
  - Some parcels of water could be much older if poorly mixed
  - High turnover time is system specific, based on water quality stability
- Mixing analysis:
  - Does not assess thermal stratification
  - Results are not valid if the tank is thermally stratified
- Results are only as good as the inputs and assumptions.
- Water quality data is the best measure of tank performance.

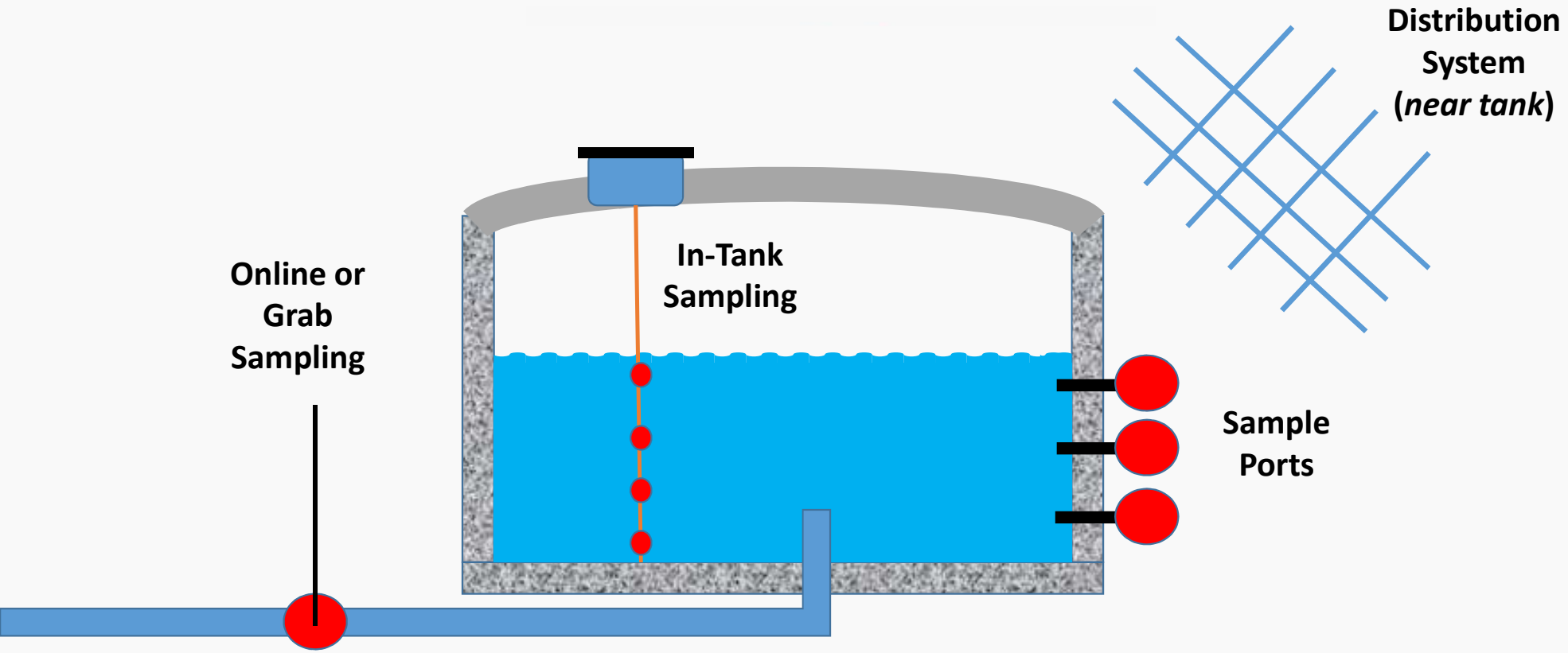
Tank Assessment Spreadsheet Example



Turnover Summary		
Avg Vol Added in One Fill Period	0.07	MG
Avg Vol Drawn in One Drain Period	0.06	MG
Avg Fill Time	0.38	days
Avg Draw Time	0.27	days
Avg Fill Rate	120	gpm
Avg Draw Rate	166	gpm
Avg Duration (Fill + Draw Time)	0.6	days
Avg Flow Rate into tank	0.10	MGD
Avg Tank Vol	1.88	MG
Turnover Time	**18.6**	**days**

Turnover Summary		
Avg Vol Added in One Fill Period	0.11	MG
Avg Vol Drawn in One Drain Period	0.15	MG
Avg Fill Time	0.50	days
Avg Draw Time	0.39	days
Avg Fill Rate	147	gpm
Avg Draw Rate	264	gpm
Avg Duration (Fill + Draw Time)	0.9	days
Avg Flow Rate into tank	0.12	MGD
Avg Tank Vol	1.82	MG
Turnover Time	**15.3**	**days**

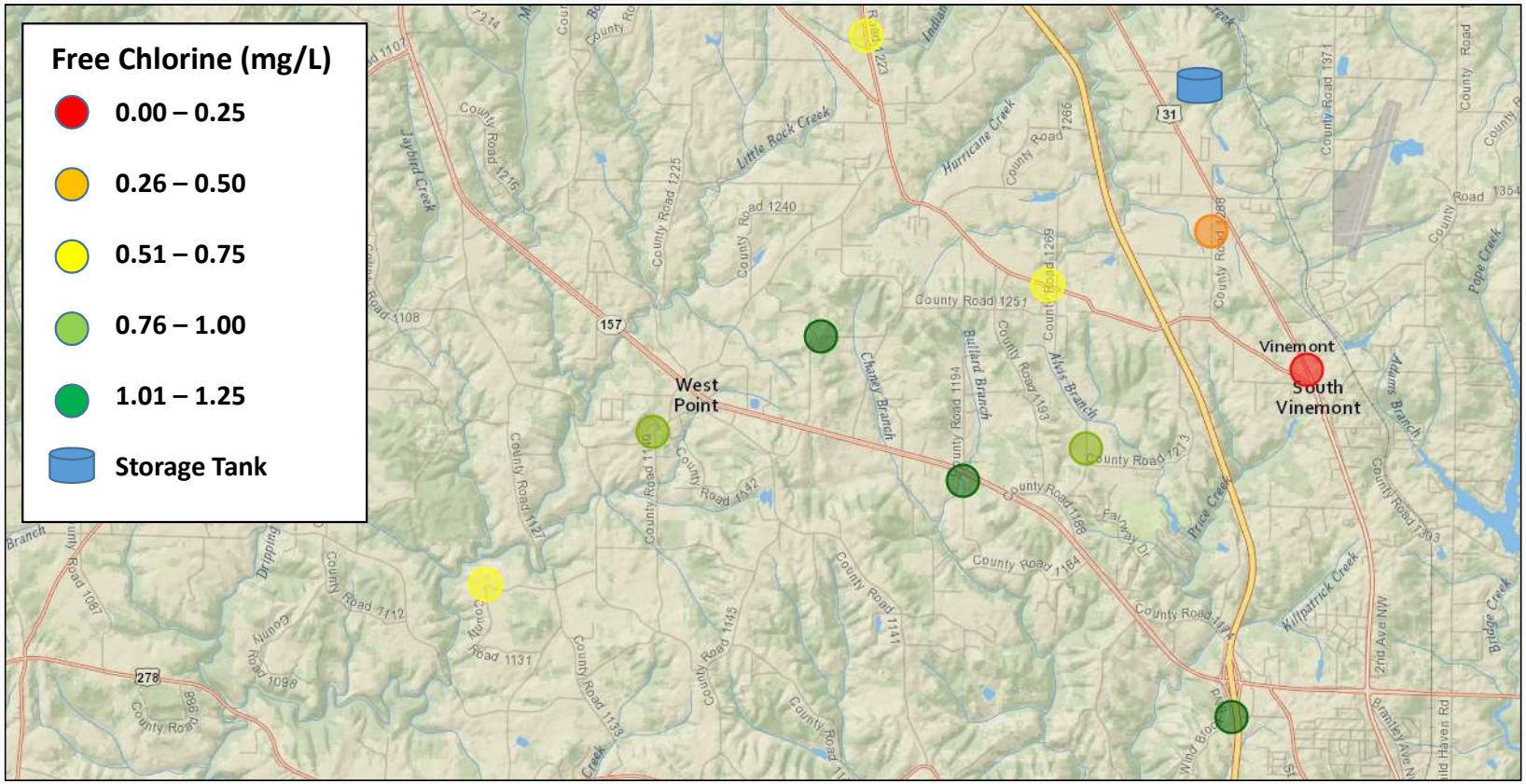
Water Quality Monitoring to Assess Tanks



Investigative Sampling Near Tanks

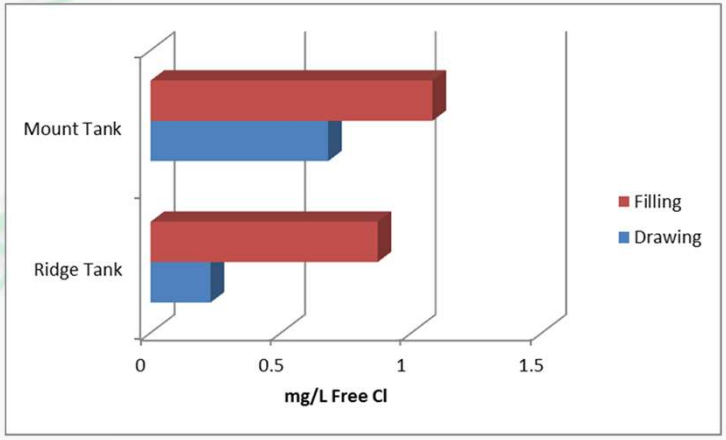
- Assess water quality by collecting grab samples in the proximity of tanks in the DS
  - Disinfectant residual, temperature, pH and DBPs
  - Sample while tank is draining
- Relatively inexpensive and immediate results
- Sample locations in the proximity of tanks may be limited to hydrants or taps at tank
- Grab sampling may not always capture variable water quality near tanks.

Investigative Sampling Example



Investigative Sampling At Tanks

- Assess water quality by collecting grab samples at the inlet / outlet of tanks
  - Disinfectant residual, temperature, pH and DBPs
  - System specific based on WQ challenges and goals
- Sample at end of fill cycle
  - Best water
- Sample at end of draw cycle
  - Worst water
- Worst case scenario to evaluate water quality degradation

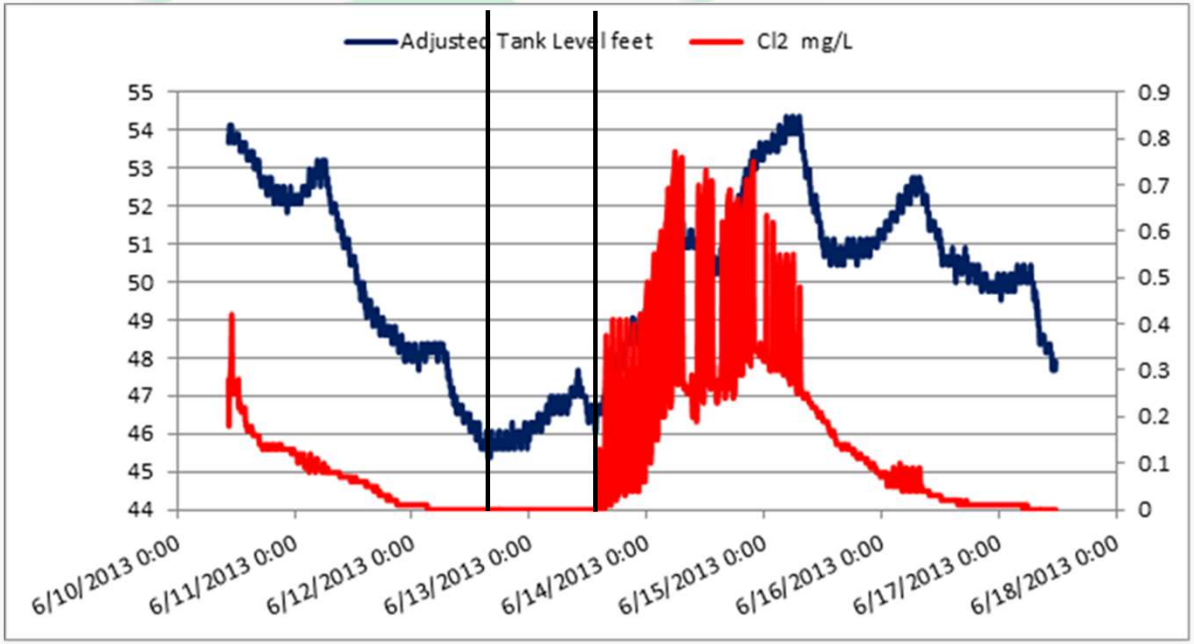


Continuous Online Monitoring

- Indirectly assess water quality within a tank by monitoring at common I/O (or outlet).
- May be installed permanently or temporarily.

Continuous Online Monitoring

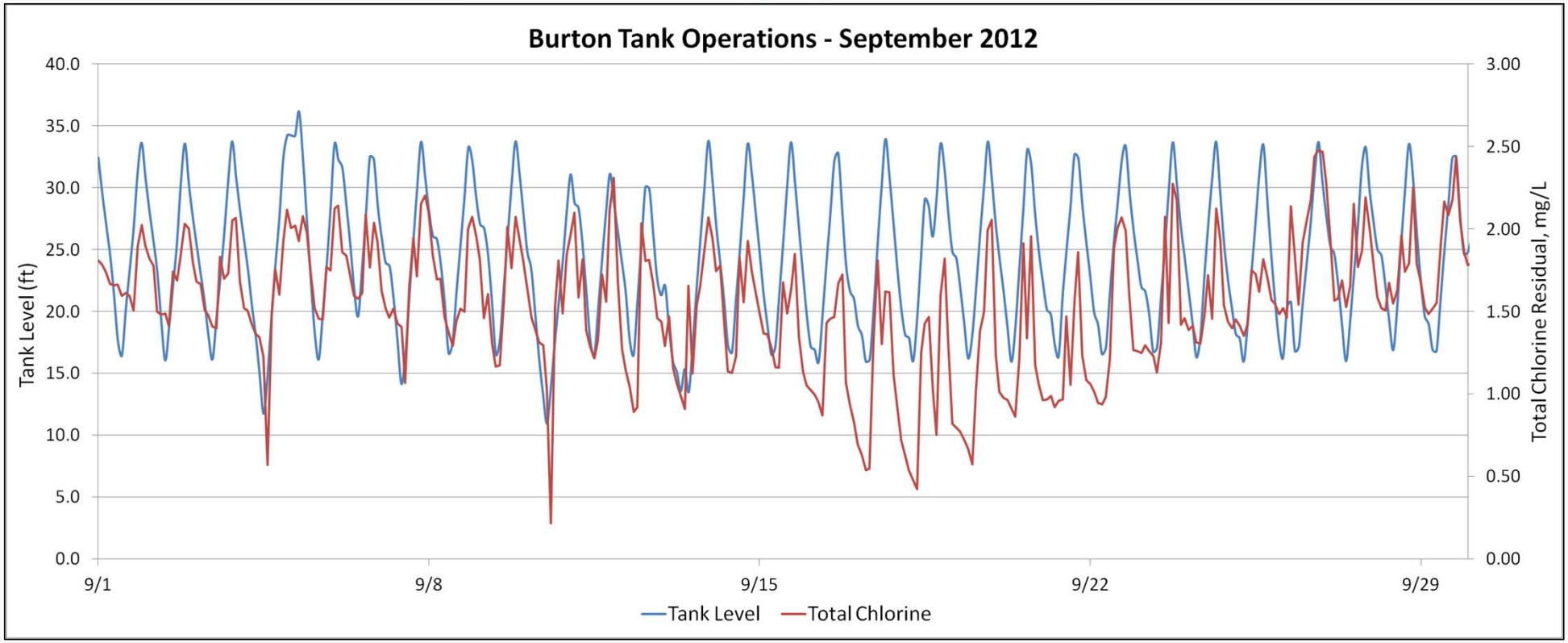
- Captures variability in water quality, as tanks cycle, that may not be captured by grab sampling.



Continuous Online Monitoring Example

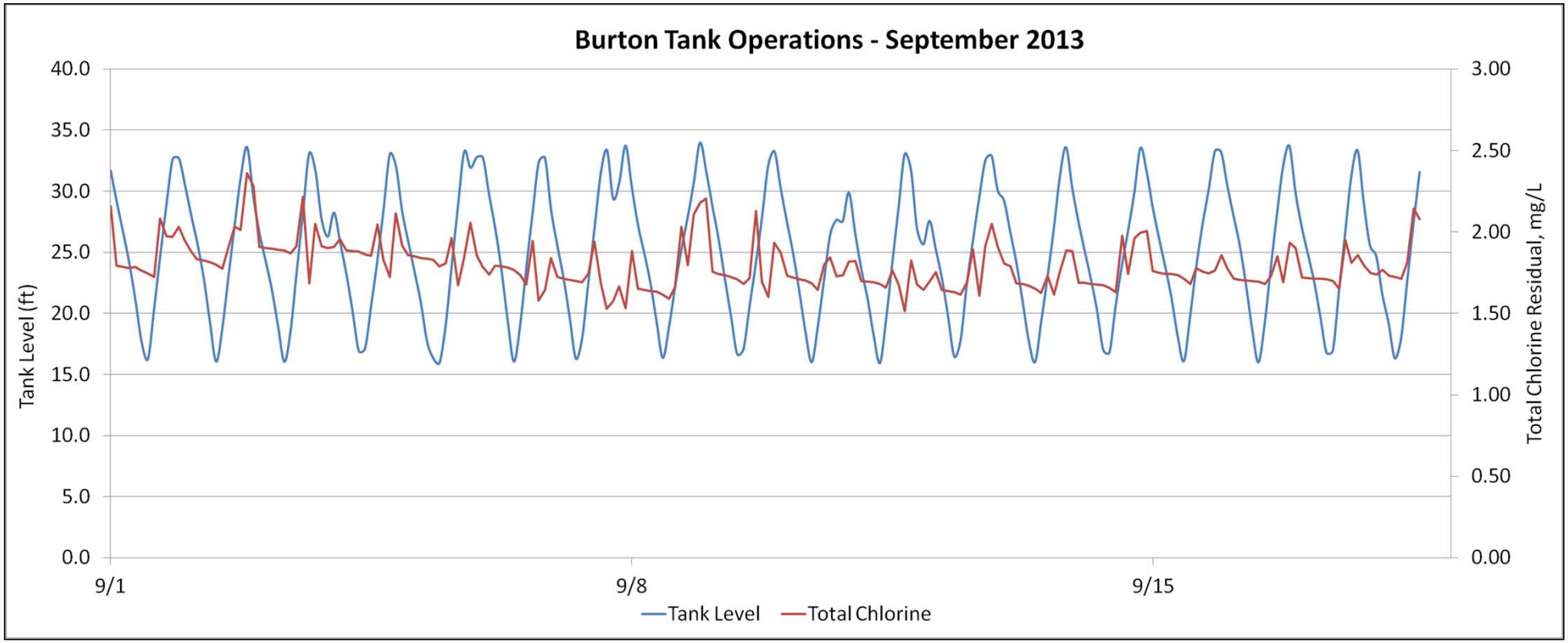
- Collected tank level and chlorine residual data from two consecutive summers.
- Elevated 0.5 MG torus-bottom tank serves rural area in northern portion of system.
- Identified as “worst performing” tank by the DS supervisor.
- Utility installed mechanical mixer after the first summer evaluation.

Online Monitoring Example: Before Mixer



Estimated Average Turnover Time = 1.45 days

Online Monitoring Example: After Mixer



Estimated Average Turnover Time = 1.4 days

Online Monitoring Considerations

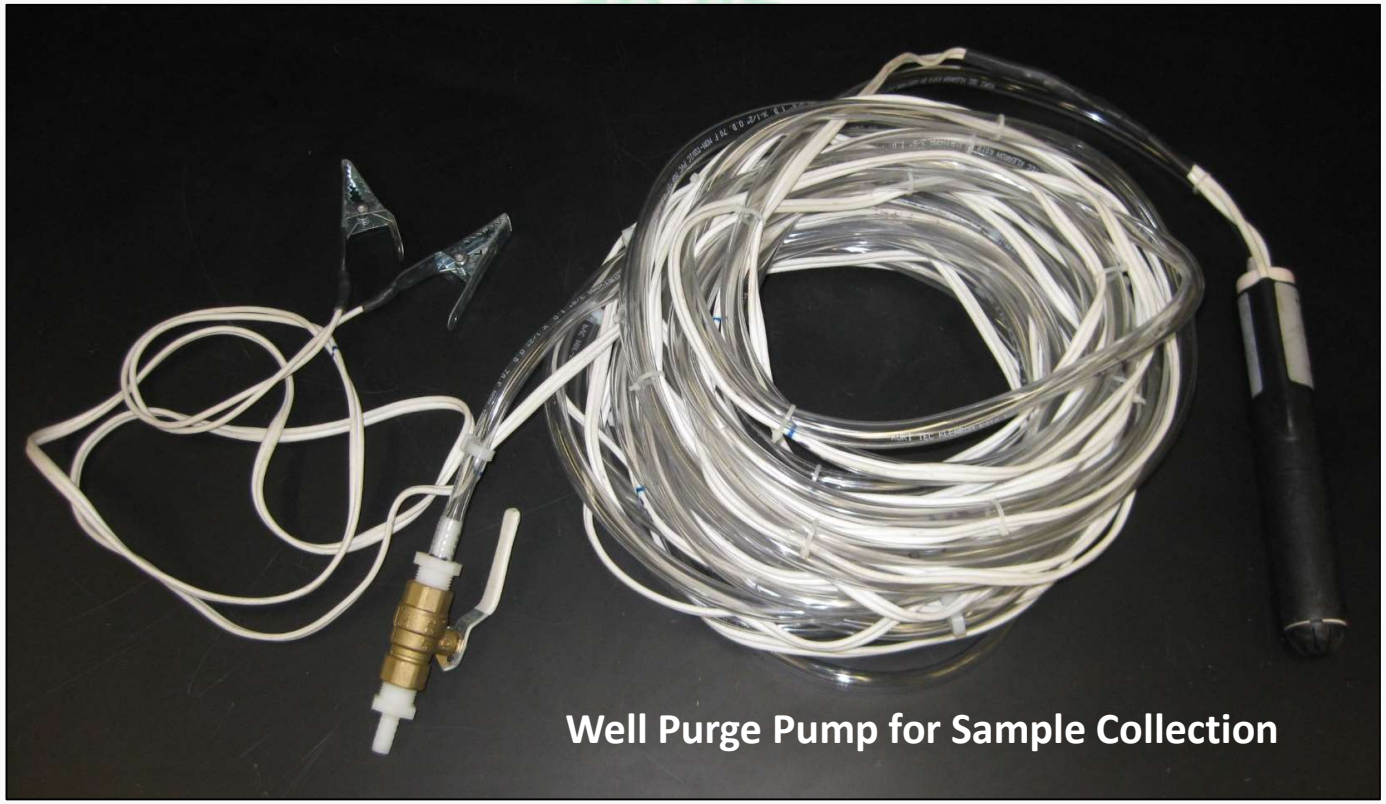
- Greater initial cost, but requires less time
- Consider pros and cons of colorimetric and amperometric monitors:
  - Sensitivity – pressure, flow, ambient temperature
  - Staff time – calibration/maintenance frequency
  - Waste stream – discharge handling
  - Power supply – solar, AC electrical outlet
  - Data Handling – remote access, local storage, SCADA
  - Others – cost, multiple parameters, interferences

In-Tank Monitoring

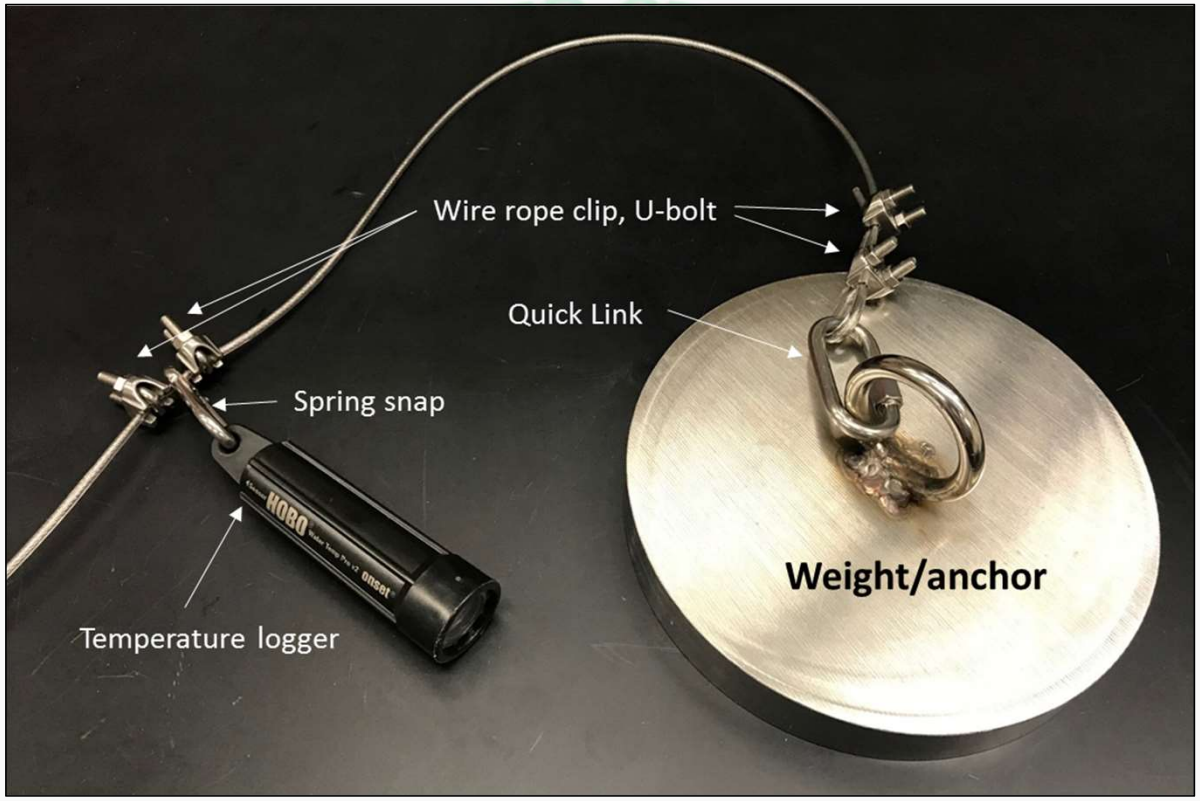
- Directly assess conditions within a tank:
  - Collect water quality grab samples at various depths.
  - Continuously monitor temperature at various depths to assess mixing performance.
- Requires monitoring equipment, safety equipment, and fall protection training.
- In-tank sampling protocol has been developed for this approach.

Fall Protection Equipment

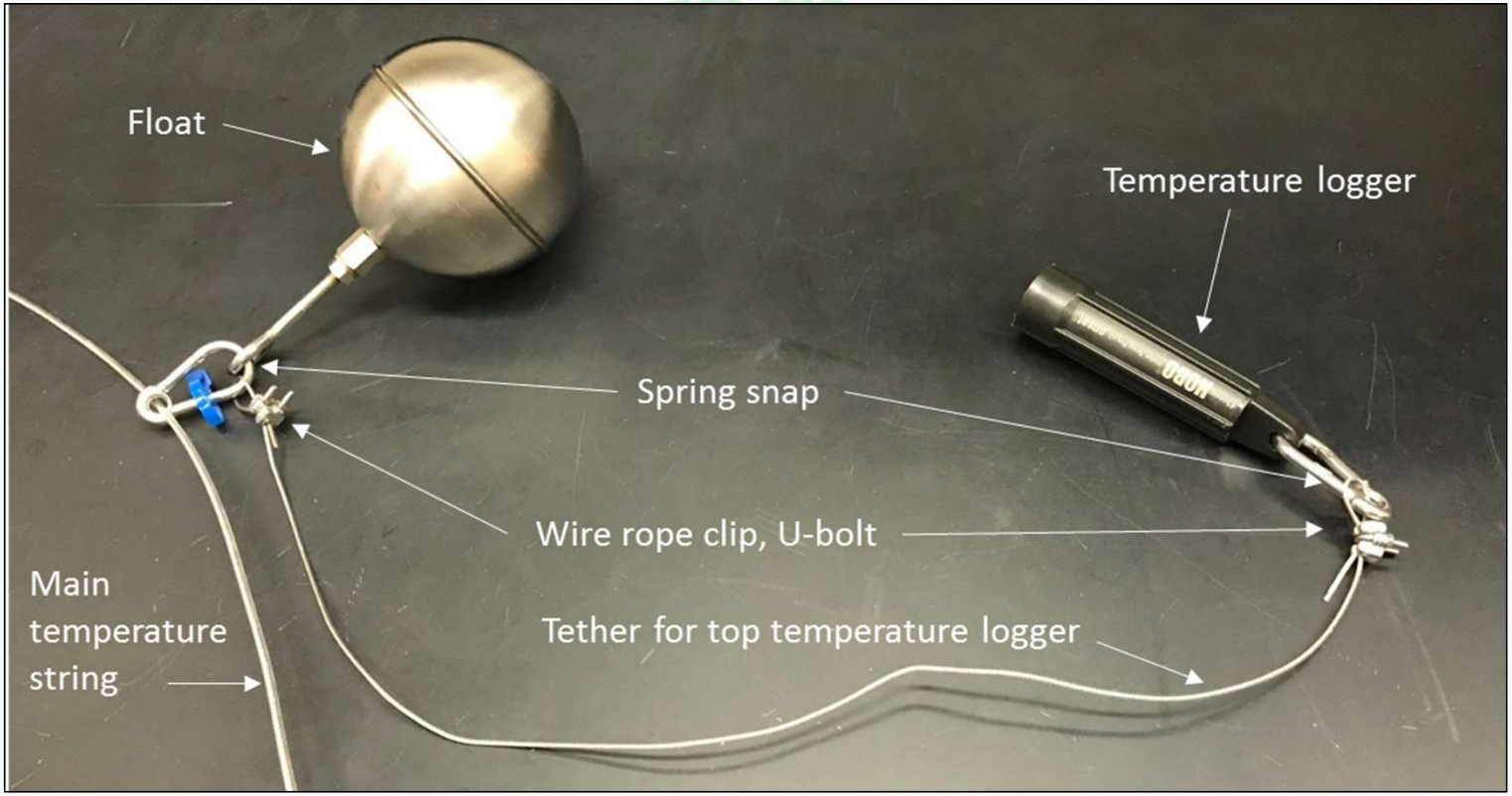
In-Tank Sample Collection Equipment



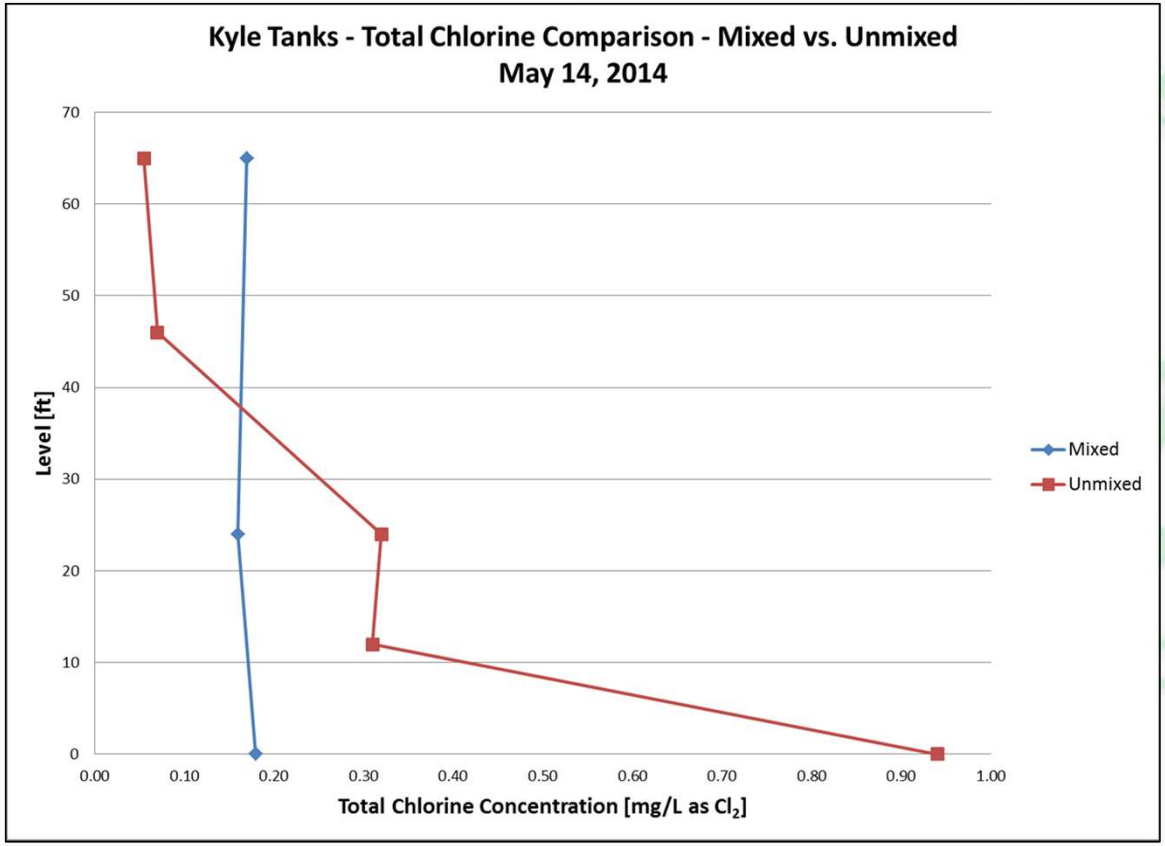
In-Tank Temperature Analysis Equipment



In-Tank Temperature Analysis Equipment

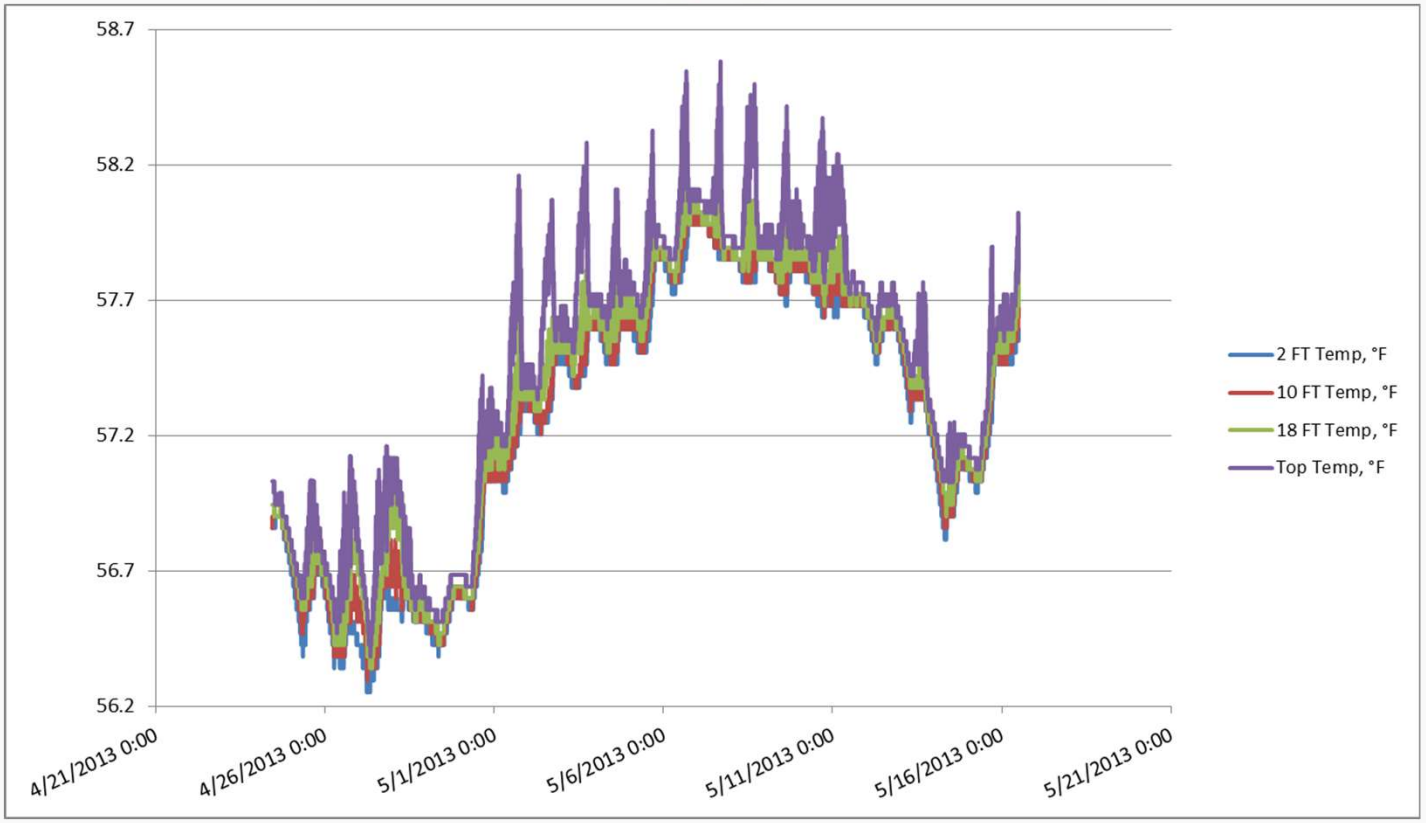


In-Tank Water Quality Monitoring Example #1

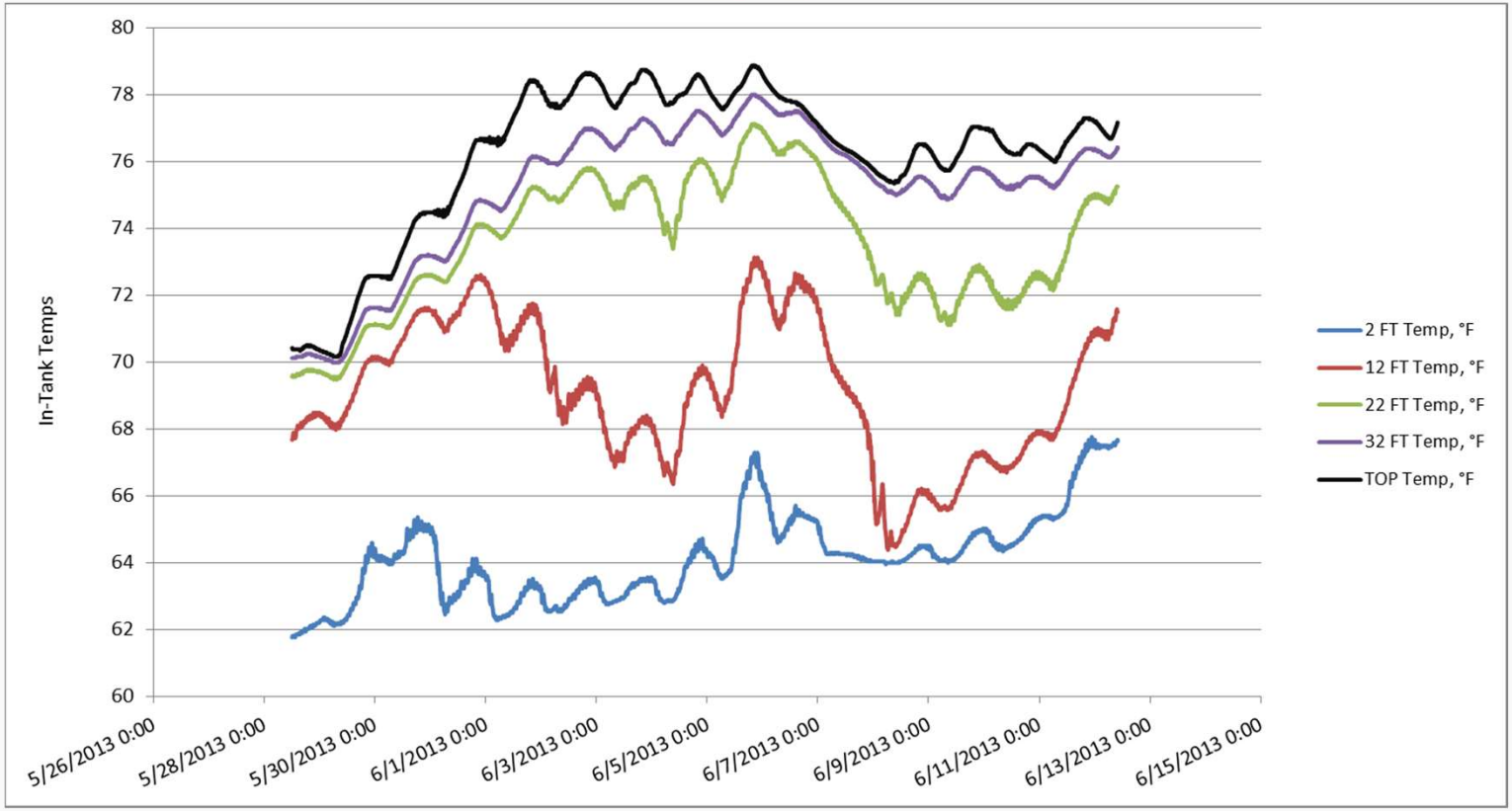


- Evaluated two side-by-side tanks
- Identical design except on tank had a mechanical mixer
- Average water age of 6.8 days

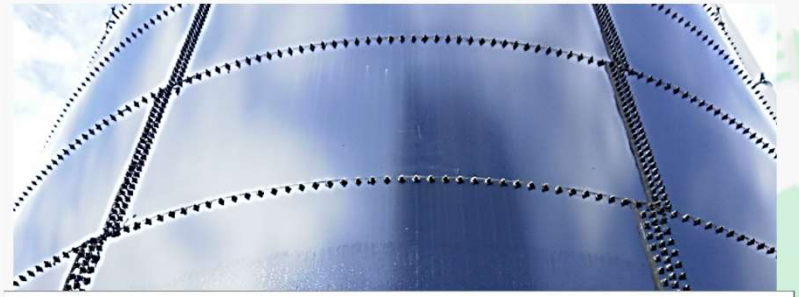
In-Tank Temperature Monitoring Example #1

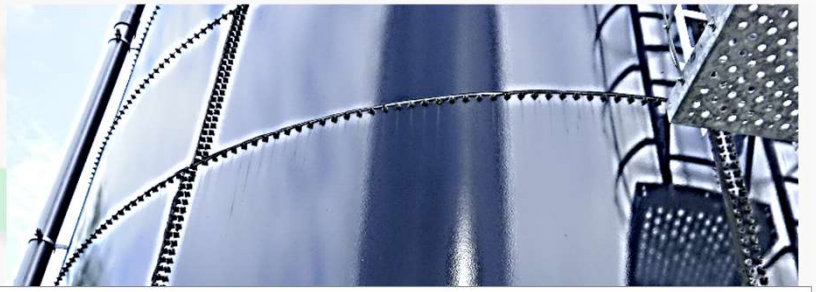


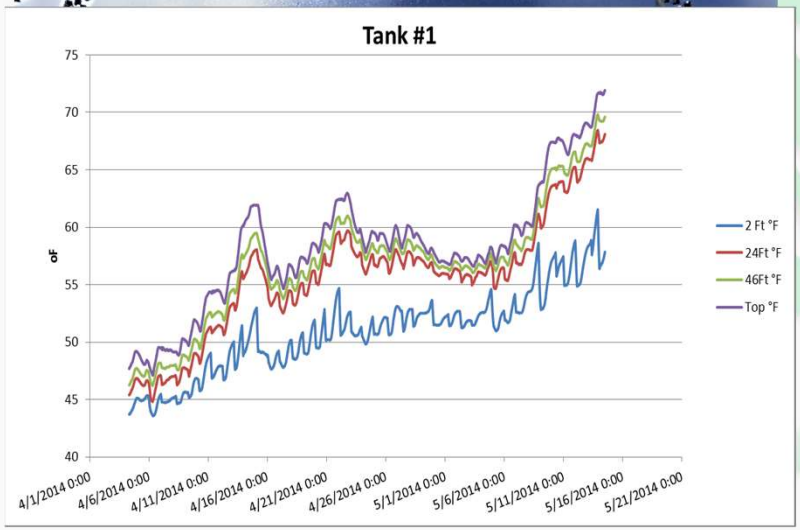
In-Tank Temperature Monitoring Example #2

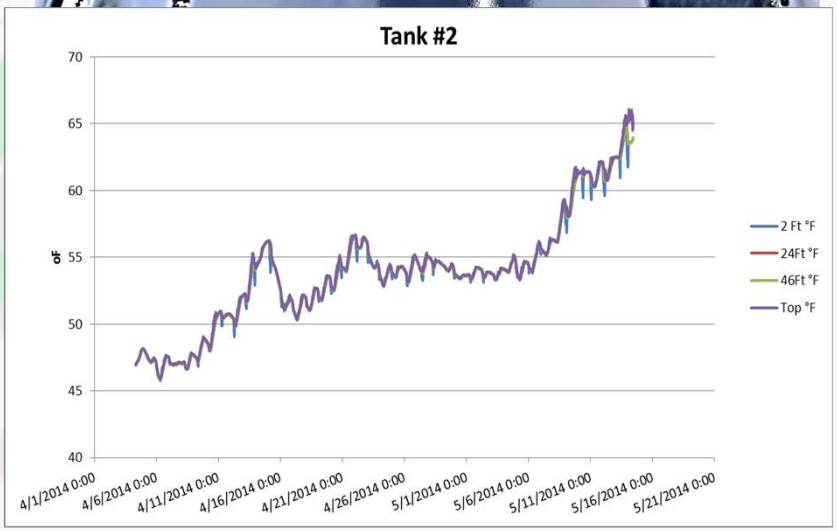


In-Tank Temperature Monitoring



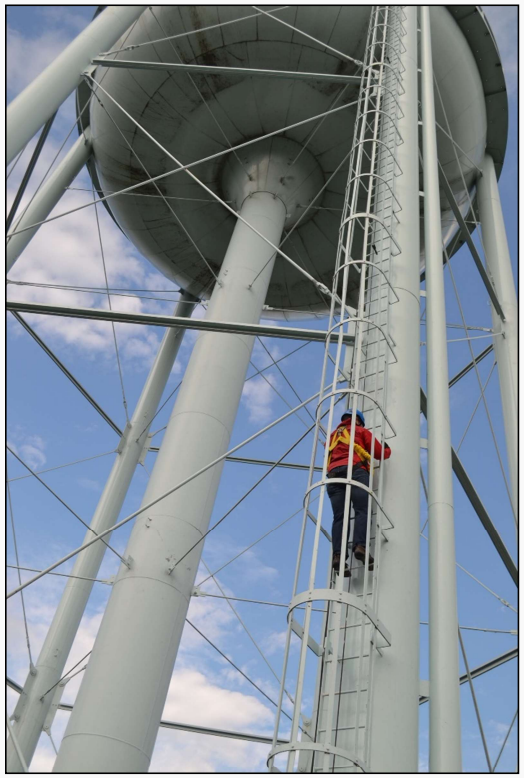






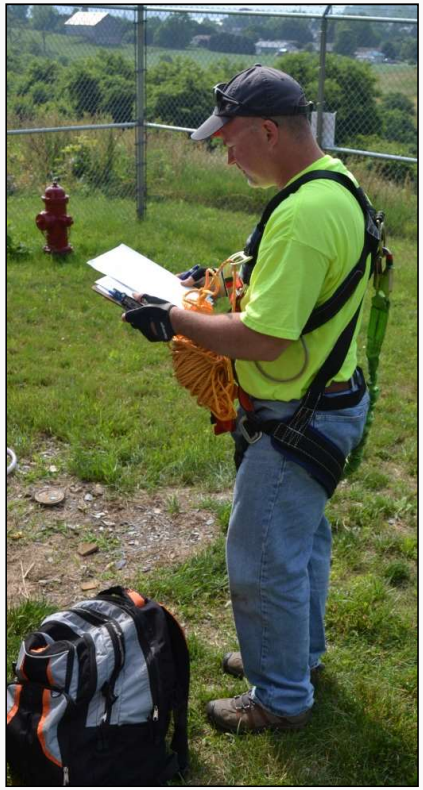
In-Tank Monitoring Considerations

- In-tank monitoring may not be feasible for some states and water systems to implement.
  - Equipment costs may be prohibitive.
  - Safety training may not be available.
  - Policies may prohibit state staff from climbing tanks.
- Consider sharing equipment to reduce cost.



Alternative In-Tank Monitoring Approaches

- Collect only water quality samples (i.e., not temperature) to reduce equipment costs.
- Collect water quality samples from only a ground sample tap and the top of the tank using a basic sample dipper.
- Install sample taps at various depths on the outside of the tank.
- Collect water quality samples from the ground by overflowing the tank



Approach to Improve Storage Tank Water Quality

- Prioritize most critical tanks:
  - Use tank spreadsheet to assess performance
  - Review historical water quality data
- Characterize water quality:
  - Investigative sampling near tank
  - Continuous online monitoring
  - In-tank monitoring
- Evaluate options to improve water quality:
  - Operational – modify tank levels, increase fill rate
  - Design – install mixer, decrease I/O diameter

Summary

- Understanding the design and operation of storage tanks is a critical aspect of assessing their performance.
- Both adequate turnover *and* mixing are necessary for good water quality.
- Preventative maintenance helps sustain water quality.
- Storage tanks are unique and their performance should be assessed individually.
- Water quality data is the best indicator of tank performance.
- Studies can be used to assess water quality impacts from tanks.

Reducing Disinfection Byproducts through Optimization

Webinar #3: Approaches to Prioritize Distribution System Optimization Efforts

May 6, 2019

Webinar #3: Learning Objectives

- Understand overall approach for the webinar series, including a brief review of information covered in the previous webinars
- Understand approaches and tools used to prioritize available distribution system DBP control strategies
  - Approaches to evaluate distribution system water quality and applicable control strategies (Presentation 2).
  - Overview of water storage tanks, including tank characteristics and how they impact water quality, as well as potential tank studies such as estimating turnover time and mixing characteristics and sampling in/around tanks to assess water quality (Presentation 3).

Question and Answer Session

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