Distribution Network Water Quality Management
“Smart Tanks”
UGSI Solutions, Inc. is one of the fastest growing and innovative companies in the water industry.

- **PAX Water Technologies**
  - PAX Tank Mixers
  - Tank Shark®

- **UGSI Chemical Feed Solutions**
  - Polyblend® Fluid Dynamics™
  - Encore® Wallace & Tiernan®

- **PSI Water Technologies**
  - Microclor® Monoclor® RCS
  - PAX TRS™ Chem Locker™
For the last several decades, water utilities have focused on bringing state-of-the-art technologies to treatment plants in an effort to improve system water quality - the next several decades will focus on the distribution network itself.

- Today, control of disinfectant residual and THM production in a drinking water plant is manageable.

- Tank systems are designed for storage and system hydraulics – not water quality management.

- Utilization of water storage tanks and reservoirs to improve delivered water quality starts with mixing:
  - THM reduction
  - Residual control
Utilities have no “free lunch” as the choice of secondary disinfectant will determine the problems they will contend with:

**Free Chlorine**

- Boosting to offset **degradation**
- **DBP formation** (THM and HAA5 issues)

**Chloramines**

- Chloramine **degradation** (ammonia formation)
- Nitrification (nitrite and nitrate MCLs)

### DBP Formation Curve

### Chloramine Degradation Curve
Water storage tanks often suffer from a lack of maintenance which exacerbates a loss of water quality

- Biofilm formation is indicative of a lack of disinfectant residual and can result in furthering coating failure as well as a source of AOB/NOB
- Compromised venting is common
- Sediment can increase disinfectant load and harbor colonies
- Infrequent maintenance reduces tank life
Chloramine usage has been problematic due to difficulty in accurately controlling ammonia and chlorine dosage in a dynamic distribution system

- Introduction of ammonia can lead to nitrification as it is a nutrient to AOB’s & NOB’s
- Over-chlorination can create chloramine variants which lead to taste and odor problems in drinking water (dichloramine and trichloramine)
- Low residual levels can also lead to costly mitigation efforts such as:
  - Chlorine burns
  - Line flushing
  - Water wasting or tank dumping
  - Tank cycling

Ammonia Oxidizing Bacteria (AOB)
Nevertheless, a “Smart Tank” is the right place for water quality intervention in a distribution network

Reservoir water quality management requires:

- Energetic mixing to de-stratify aging water and ensure tank homogeneity
- Effective monitoring to ensure real-time water quality understanding
- Accurate dosing of chemicals at the right time in the right amount
- Strong process control with feedback for optimization of consumable use
Un-mixed tanks suffer from temperature and chemical stratification which creates a cascade of issues.

**Effective tank mixing:**

- Better distribution of disinfectant throughout the tank that can reduce biofilm risk and ensure consistent effluent residual.
- Lower overall water temperature that is favorable for residual longevity.
- Decreased sediment accumulation in tank.
- Prevention of destructive ice formation.
Properly sized active tank mixing eliminates tank stratification

Trial started 9/6/16 - Mixer Sold 11/7/16

Fill Cycles
Effective mixing can come in a variety of configurations depending upon process objective and site constraints

Tank Shark® Eductor Mixer

PAX Jet Mixer

PAX Impeller Mixer
Mixer choice depends on process objective with consideration of available power, turnover, geometry, climate and dosing needs

For Example:

- Mixer must achieve mixed tank within cycle-time of tank (mixing has to be faster than rate water enters and leaves the tank)

- De-stratification, ice-prevention, chemical dosing, THM aeration all require different mixer capacity and power
THM Reduction: Starts with Strong Mixing

“Smart Tanks”
THM’s in distribution systems are caused by raw water organic content, chlorine dose and water age

- THMs (Trihalomethanes) – most common regulated DBP (Disinfection By Product)
- Formed during the reaction between natural organic matter in raw water and chlorine disinfectant
  - Function of raw water quality (TOC, Bromide)
  - Function of chlorine concentration
  - Function of water age
    - Oldest water = Highest THMs
  - Function of water temperature
There are four general strategies to deal with THMs: change disinfectant (to chloramines), reduce NOM (naturally occurring organic material), reduce water age, or remove THMs after they form.

**PAX TRS™ removes THMs by tank aeration after they form**

TIME

Free Chlorine (Cl) + Natural Organic Matter (NOM) = Disinfection Byproducts (DBP)
THMs are volatile.. just like CO$_2$

- THMs would rather be in gas phase than liquid phase
- The *driving force* for mass transfer from liquid phase to gas phase is based on a difference in concentration between THMs in the water and THMs in the air
- THMs can build up in the headspace of a tank if its not actively ventilated, stopping THM volatilization (Henry’s Law)
- Optimizing a tank to volatilize THMs can be simple or complex, depending on the tank conditions, the amount of treatment needed and energy contraints/cost
Henry’s Law limits passive THM removal, but active mixing allows THM’s to bridge the diffusional barrier

But you need **STRONG** mixing
Adding active ventilation breaks Henry’s Law equilibrium in tank head-space
Achieving THM reduction across a system requires treatment at different points with treatment at the clearwell or at tanks.
Colorado Springs – Cedar Heights Tank 3
Mixing and TTHM Removal

- Ground storage (all above ground)
- Round, welded steel construction
- Diameter: 52’-0”, Height: 16’-0”
- Rated volume: 0.25 MG
- 24” diameter hatch located on top
- Average total flow through tank: 33,000 Gal/Day
- Separate inlet/outlet pipes
- Cathodic protection buoy in tank center
- 120 V, Single phase power available at tank

THM removal required = 25% or greater
Colorado Springs – Project Schedule and Scope of Supply

**Project Schedule**

Bid Date: October 31, 2017  
Notice to Proceed: December 13, 2017  
Installation Complete: December 16, 2017  
System Validation: January 30, 2018
# Colorado Springs – Distribution System Results

<table>
<thead>
<tr>
<th>Location</th>
<th>TTHM AVG (Before Install)</th>
<th>TTHM AVG (After Install)</th>
<th>Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar Heights Tank</td>
<td>54.0 ug/L</td>
<td>31.1 ug/L</td>
<td>42%</td>
</tr>
<tr>
<td>LRAA Sample Site #1</td>
<td>57.5 ug/L</td>
<td>30.0 ug/L</td>
<td>48%</td>
</tr>
</tbody>
</table>

**Mixer + PowerVent® at Cedar Heights Tank**

**LRAA Sample Site #1**
Ryan Ranch Tank - Monterey, CA

- Ryan Ranch Tank: 0.5MG, 72’ D, 16’ H – end of line, low turnover
- THM levels average 140 µg/L in tank, max 50 µg/L outside Ryan Ranch
- Three quarters of elevated levels, to avoid violation (RAA < 80 µg/L), sample needs to be just around 50 µg/L in Q3-2011
- Estimate w/o intervention: 140 µg/l
- Low Cl – periodic dosing onsite
- Limited power at tank -20 amps

Goal: 60% THM Reduction

- Wash out tank
- Chemical clean
- Mix tank – PAX PWM 400 mixer
- Evacuate head space – PAX PowerVent fan system
Ryan Ranch project execution over two week period of PAX TRS™ system
Initial results of Q3 compliance test showed 49.2 µg/L with RAA at 79.3 µg/L!

- 2010 Avg = 140
- 2011 Avg = 51
- 2012 Avg = 47
Surface aeration is a good method to treat THMs in tanks, but proper equipment selection is key

- Surface Aeration is energy efficient
- Adding surface aerators to a tank is relatively easy (with PAX Water equipment)
- Maintaining surface aerators in a tank can be a problematic
  - Some systems have nozzles that clog (mesh too fine)
  - Maintaining the equipment can require divers and a crane
  - PAX surface aerators require no maintenance and have clog proof nozzles that can pass up to 3 inch solids (highly specifiable)
- Some surface aerators are more efficient than others
  - The cost of energy usually outweighs the capital cost of the equipment over time
  - This is an important difference that customers appreciate
PAX TRS™ installations are straightforward and do not require extensive tank modifications.
Disinfectant Residual Control: Starts with *Strong* Mixing

“*Smart Tanks*”
Increased focus on reducing violations in distribution networks is here...

Violations of the Safe Drinking Water Act

Violations were reported in most US counties, according to 2015 EPA data analyzed by environmental advocacy group the Natural Resources Defense Council. The size of the circles in the map corresponds to the number of reported violations.

For current information of violations in your community, you can access the EPA’s Safe Drinking Water Information System database.

Source: NRDC

“Beginning April 29, 2019, a community water system using a chemical disinfectant or that delivers water that has been treated with a chemical disinfectant shall maintain a minimum residual disinfectant concentration throughout the distribution system sufficient to assure compliance with the microbiological MCLs and the treatment technique requirements specified in § 109.202. The minimum residual disinfectant concentration is 0.2 mg/L”

- TX and LA have **0.5mg/l** mandatory residuals
- CO has implemented **0.2mg/l** in 2019
AWWA Disinfection Committee conducted a survey in regards to disinfection practices to water systems throughout the United States in 2017

- Fifth survey conducted by the committee (approximately every ten years since 1978)
- 375 community water systems representing 44 states took part
- Data is based on 2016 calendar year
- Purpose is to inform common disinfection treatment practices, challenges and impacts of the regulatory requirements in drinking water industry.
Most respondents claimed never having difficulty in meeting target free chlorine residuals for **primary disinfection**. Roughly 35% respondents claimed having an occasional difficulty or greater.

Frequency at which respondents report difficulty in meeting target free chlorine residuals for primary disinfection (n = 270)
Approximately 60% respondents claimed having difficulty meeting secondary disinfection target occasionally or greater

Frequency at which respondents report difficulty in meeting target free chlorine residuals for secondary disinfection (n = 269)
Chlorine gas and sodium hypochlorite (bleach) when combined with water rapidly form the powerful disinfectant hypochlorous acid (and the hypochlorite ion)

\[
\text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{H}^+ + \text{Cl}^-
\]

\[
\text{NaOCl} + \text{H}_2\text{O} \rightarrow \text{Na}^+ + \text{HOCl} + \text{OH}^-
\]

\[
\text{HOCl} \leftrightharpoons -\text{OCl}^- + \text{H}^+
\]

Hypochlorous acid (HOCl) and the Hypochlorite ion (\(\cdot\text{OCl}\)) in water with pH 6.5-8.5 exist in equilibrium with both species present.
Both hypochlorous acid and the hypochlorite ion are strong disinfectants with the ion being slightly weaker than the acid at low pH.

![Graph showing the percentage of HOCl or OCl⁻ vs pH]

% of HOCl or OCl⁻

0% 20% 40% 60% 80% 100%

pH 4 5 6 7 8 9 10 11

HOCl OCl⁻

KILL

Nitrosomonas sp. TNE100株
The Breakpoint Curve: know where you are on the curve

Chlorine Residual

Iron
Manganese
Nitrite

NOM
Ammonia

Trihalomethanes

monochloramine

Combined Chlorine

Chlorine Added

5:1
Cl₂:NH₃-N

Breakpoint

Free Available Residual
In a “real world” water system, free chlorine levels are challenged by a number of factors:

- Temperature stratification in reservoirs and tanks
- Chemical stratification in reservoirs and tanks
- Imported or mixed water compatibility
- Poor condition of distribution pipelines
- Water aging in pipelines and reservoirs
- Concern over THM formation
Ramping-up chlorine levels of plant produced water may improve residual levels at the edges of a network, but this strategy will also encourage or increase THM formation in the system over time.
Northglenn, CO: Mixers add stability to disinfectant residuals and allowed for lower plant chlorine dosing

- In summer months, Northglenn increased residual (free-chlorine) plant exit values to 1.4ppm to offset loss in the network
- Increased free chlorine levels resulted in higher rates of THM formation
- By adding mixers, the utility observed higher and more uniform network residuals and no longer needed to increase plant exit residuals – thereby lowering THM formation risk

Adding appropriate mixing energy to tank ensures tank is de-stratified and exhibits consistent residual
Utilizing water storage tanks as chlorine residual intervention points is a best practice; more effective than “in-line” boosting

- Tanks are a source of chlorine demand (sediment, bio-film etc.) – solve issue at source
- Tank volume provides a convenient “buffer” allowing a safe place to add chlorine and monitor before subsequent network experiences chlorine dose
  - Allows option to valve-off
  - Allows holding for adjustment
- Mixing of entire volume is ensured versus dosing into a pipe
Four criteria must be met for proper chlorine residual control in reservoirs:

1. Proper mixing to ensure a homogenous water body that will not stratify
2. Accurate dosing of chlorine to ensure adequate dose for desired position on the breakpoint curve
3. High energy mixing that ensures instantaneous reaction of introduced chlorine with compounds that create chlorine demand
4. Real-time monitoring and control logic to maintain or achieve equilibrium by responding to dynamic reservoir conditions
Residual control systems can be fully automated with automatic dosing of chlorine and/or ammonia based on the real-time determination of where the tank chemistry is on the break-point curve.
Chloramine residual control systems can take on a number of different configurations depending on tank particulars and client preferences.
The Chemlocker® is an example of a smart boosting station that safely offers customers a water quality monitoring and disinfectant boosting complete with mixing and on-line monitoring – where a more automated approach is not necessary on a full-time basis.

Chemical dosing through venturi eductor – no dosing pumps
Halifax, Canada – 9 MG ground storage tank with consistent chlorine residual issues (influent was 0.7ppm with decay to 0.3ppm in warmer months)
Demonstration SmartBoost™ trailer in summer of 2018 managed residual to desired 0.7 ppm immediately

- 100 gpm Tank Shark® mixer
- Microclor® 60 PPD OSHG as free chlorine source
Benicia, CA – 2 MG ground storage tank with consistent chlorine residual issues (<0.6ppm)
Notice correlation of water depth with residual

September 2013 (Baseline)

Chlorine residual (mg/L)

Water level (ft)

PAX Water Technologies
Company Confidential
SmartBoost™ controllers, water quality analyzers and pump skids in fiberglass building
Chlorine residual in control and boosted significantly as required

February/March 2014

Set-point change

Chlorine Drum empty
Chlorine residual in control and boosted significantly as required (weekly samples)
Maintaining disinfectant residuals > 2.3 ppm effectively controls nitrite levels

Elevated nitrite levels when total chlorine residual is low

Total chlorine > 2.3 mg/L to avoid nitrification risk
These results are consistent with research on distribution network “biostability”

- Biological growth in a network is governed by inactivation due to disinfectant levels (total chlorine) and availability of a food source (ammonia)
- There is some level of disinfectant residual that will limit pathogen growth in a water distribution network

Distribution Network Water Quality Management

“Smart Tanks”