Lowering THMs in Your Distribution System Using In-Tank Aeration

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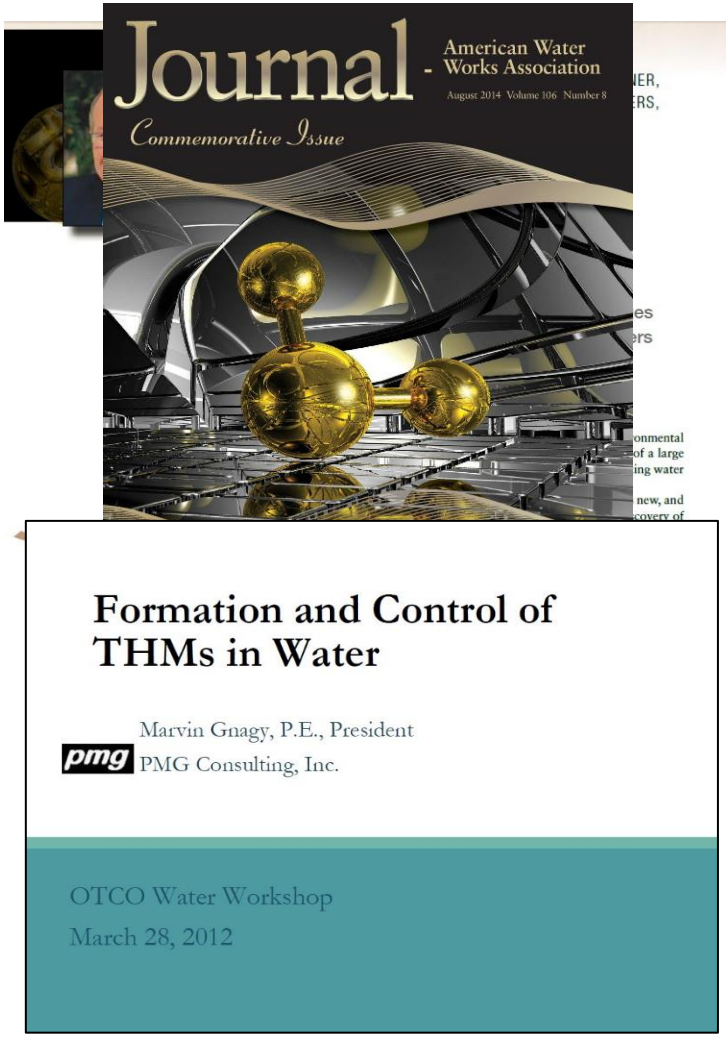
Dr. Peter S. Fiske
PAX Water Technologies, Inc.

Some great resources…

- McGuire et al., August 2014
  - 20-page JAWWA article summarizing the history and current best practices for addressing DBPs

- Marvin Gnagy's 2012 slides on DBPs, their precursors and formation, and treatment options
  - Google Search: "Gnagy Formation and Control of THMs"



THMs in the Distribution System

- THMs (Trihalomethanes) – most common regulated DBP (Disinfection By-Product)
- Formed from the reaction between natural organic matter in your raw water and Cl disinfectant
  - Function of raw water quality (TOC, Bromide)
  - Function of Cl concentration
  - Function of water age
    - Oldest water = highest THMs

Typical Approach to DBP reduction

- Lower the organic matter in raw water
  - GAC, Miex, Filtration, RO (get the organics OUT!)
  - Improve raw water source (new source?)
- Change the chemistry of disinfection
  - Change primary disinfection (ozone, UV, etc.)
  - Change secondary disinfection (chloramines)

Problem: All these options are VERY expensive!
(big changes to your water system)

What is post-treatment aeration or air stripping?

- Exposing water to air
- Volatile chemicals in the water evaporate into the air

Advantages of post-treatment aeration

- Deal with THMs where they are highest
- Lower cost than systemic changes
- Much quicker solution [regulatory compliance]
- Some added water quality benefits (mixing, lowered VOCs, lowered CO_2, lowered H_2S…)

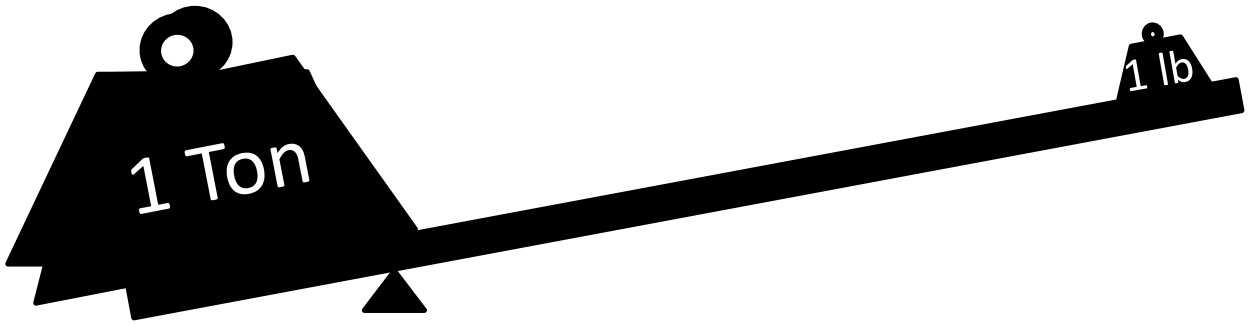
Key Point: Post-treatment aeration can LOWER cost of other system-wide treatment changes

Key Benefit: In-tank aeration can lower treatment plant operating costs

- Lowers peak THM levels at highest points in the distribution system
  - Lowers peak capacity requirements at treatment plant
- Reduces the frequency of GAC media replacement
  - Takes some of the “load” off treatment plant
- Can be applied only when THMs are highest
  - Cut energy cost

Treatment plant “lift”

Distribution system “lift”



Aeration to remove THMs is not new…

Table 1. Simulated Aquarium Test

Aeration reduced THMs 85 percent in Solano Irrigation District's aquarium test.

Date	Time	Sample Location	THM Result	Difference
10/25/2006	10:10	Aquarium before aeration	151 µg/L	-85%
10/25/2006	12:55	Aquarium after aeration	23.2 µg/L	

Table 2. Full-Scale Storage Tank Test

Aeration at SSWA's Gregory Hill Storage Tank reduced THMs 70 percent.

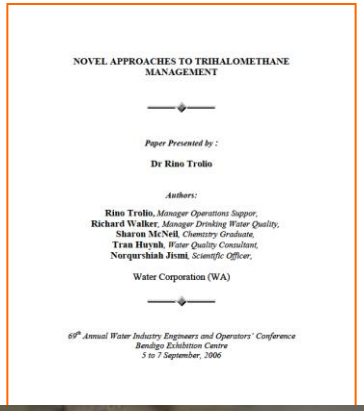
Date	Time	Sample Location	THM Result	Difference
1/5/2007	11:00	Tank before aeration	120 µg/L	-70%
1/15/2007	10:20	Tank after aeration	36.4 µg/L	

Treatment

Storage Tank Aeration Eliminates

Trihalomethanes

In anticipation of the Stage 2 Disinfection Byproducts Rule's more stringent requirements, a California water association found a simple solution for eliminating treatment by-products.



NOVEL APPROACHES TO TRIHALOMETHANE MANAGEMENT

Paper Presented by :

Dr Rino Trolio

Authors:

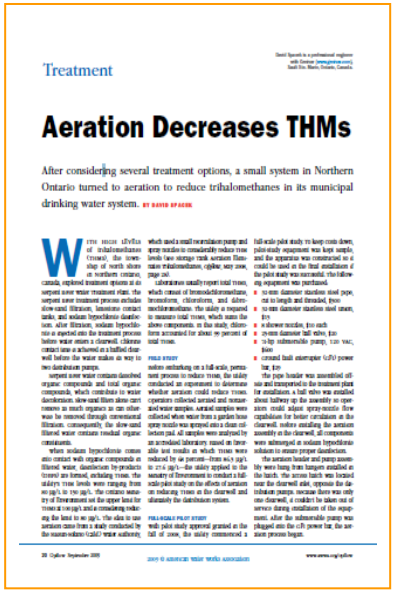
Rino Trolio, *Manager Operations Suppor,*
Richard Walker, *Manager Drinking Water Quality,*
Sharon McNeil, *Chemistry Graduate,*
Tran Huynh, *Water Quality Consultant,*
Norqurshiah Jismi, *Scientific Officer,*

Water Corporation (WA)

69th Annual Water Industry Engineers and Operators' Conference
Bendigo Exhibition Centre
5 to 7 September, 2006

Figure 2: *Aeration at Denmark Horsley Road Reservoir*

Installation of the continuous aeration system in Horsley Road Reservoir, resulted in a reduction in the average THM concentrations value from 218 µg/L to 73 µg/L.



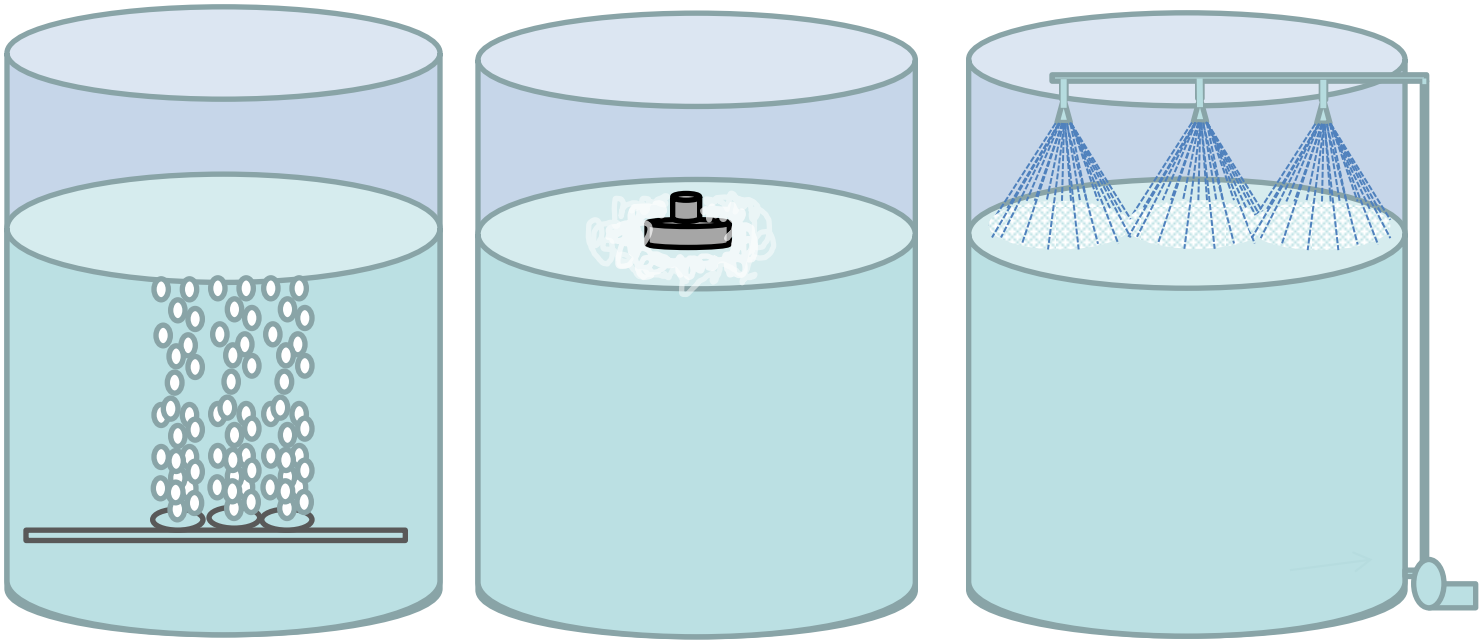
Treatment

Aeration Decreases THMs

After considering several treatment options, a small system in Northern Ontario turned to aeration to reduce trihalomethanes in its municipal drinking water system.

Aeration has been PROVEN to work

Different In-tank Aeration Technologies

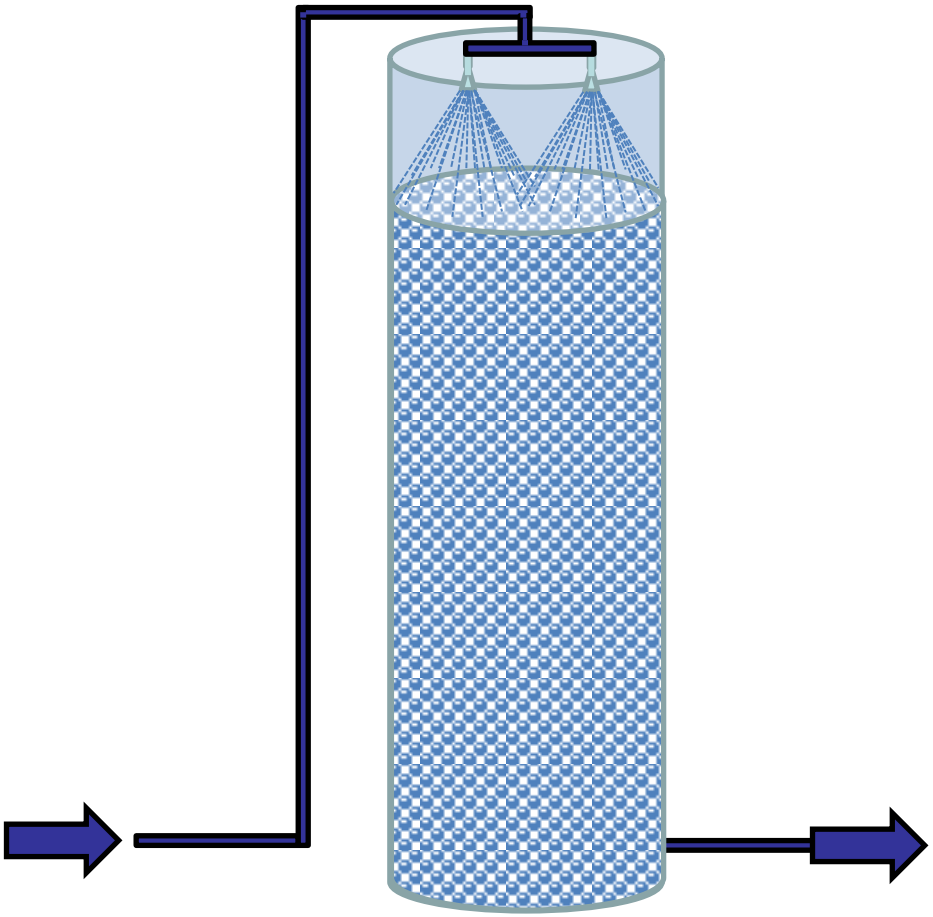


Bubble aeration Surface aeration Spray aeration

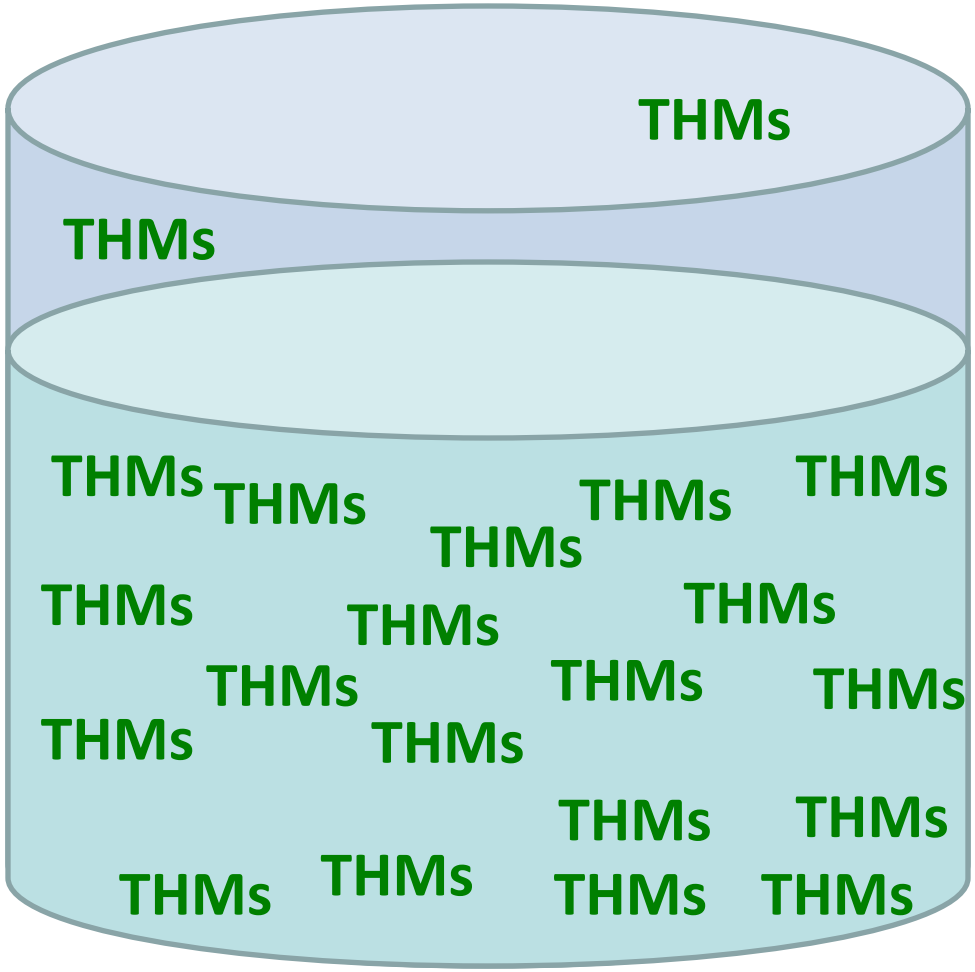
Any of these technologies can be made to work…
but capital and energy costs vary greatly

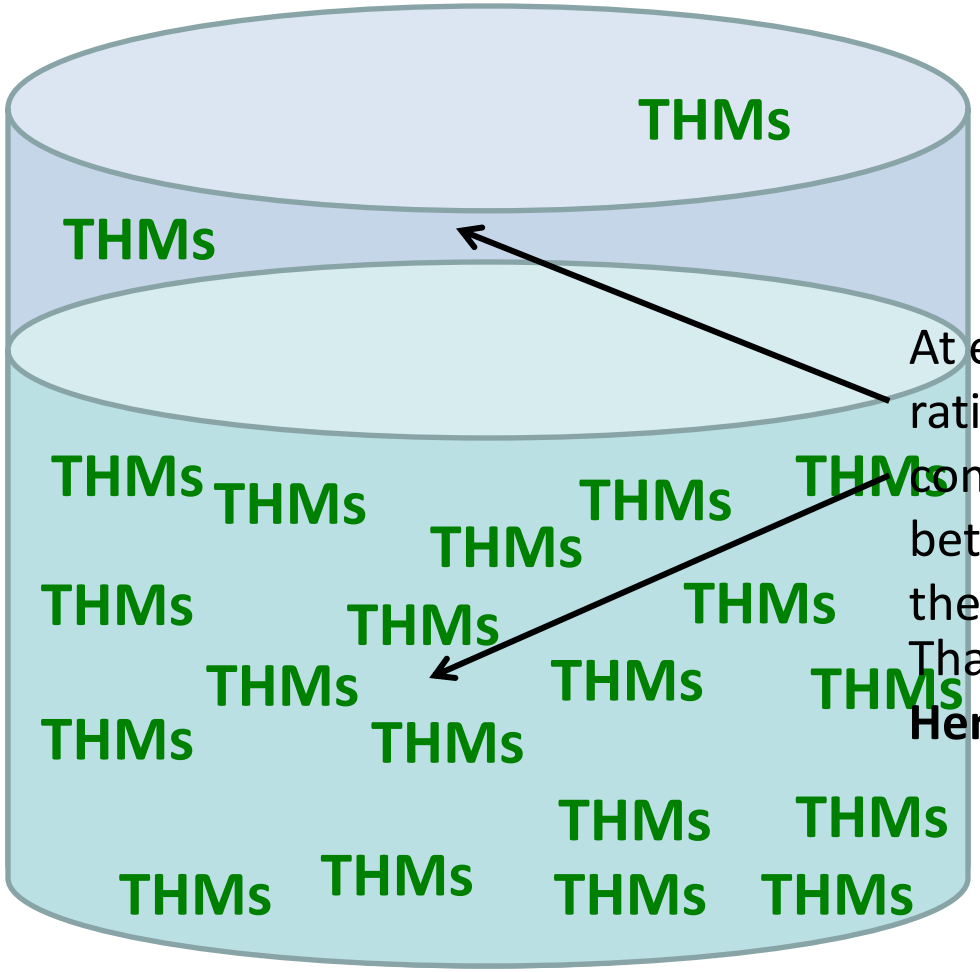
There is also Packed Tower Aeration

- Not an “in-Tank aeration system
  - Requires it’s own “tank”
- Few reported applications of PTA for THMs
- Probably high capital and energy costs



Aeration - starts with evaporation





At equilibrium, a ratio in THM concentration between the air and the water

That ratio is the **Henry's Law constant**

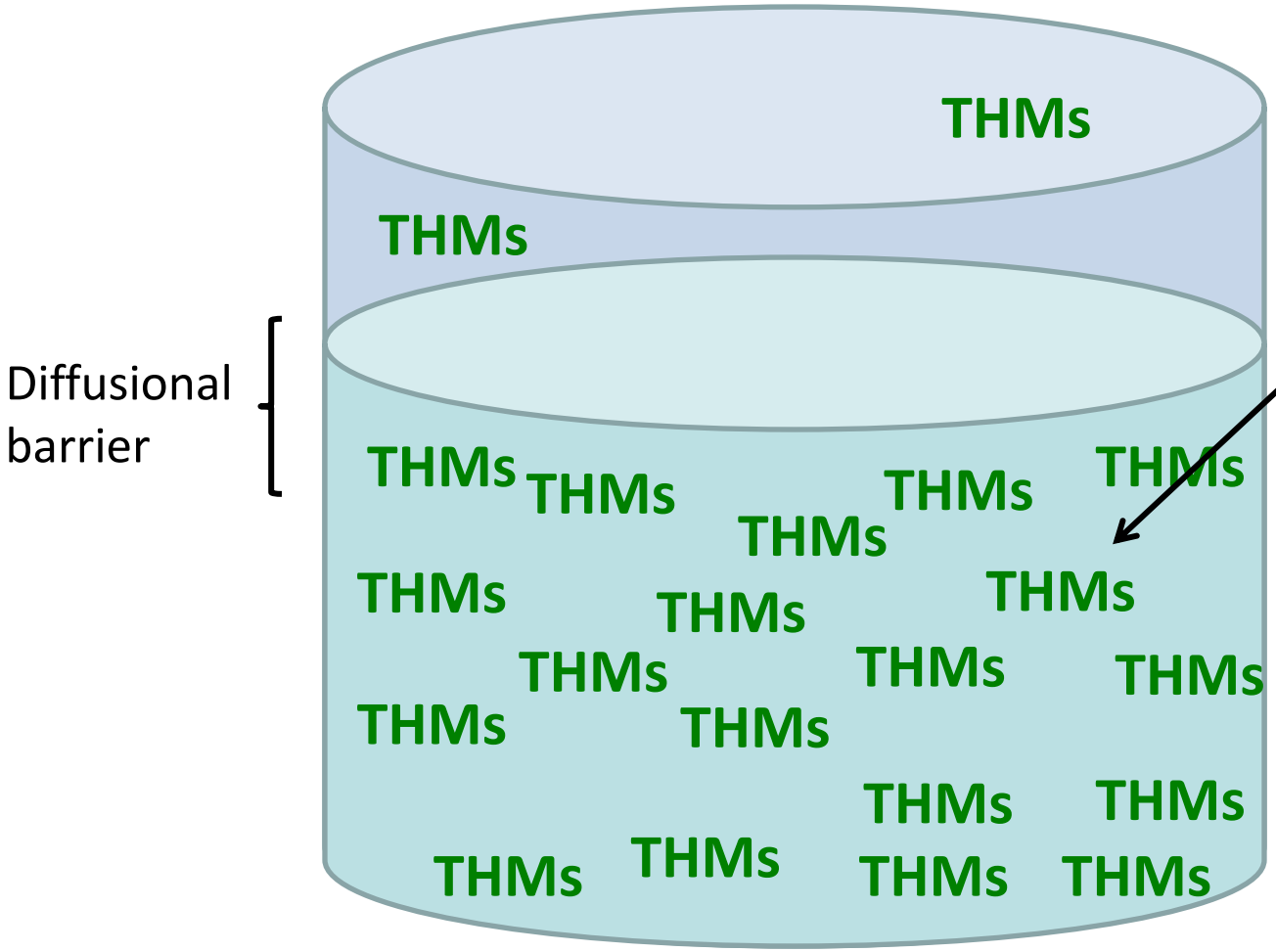
Henry's Law constants for THMs

THM species	Henry's law constant @ 20 °C
Chloroform	0.13
Bromodichloromethane	0.08
Chlorodibromomethane	0.04
Bromoform	0.02

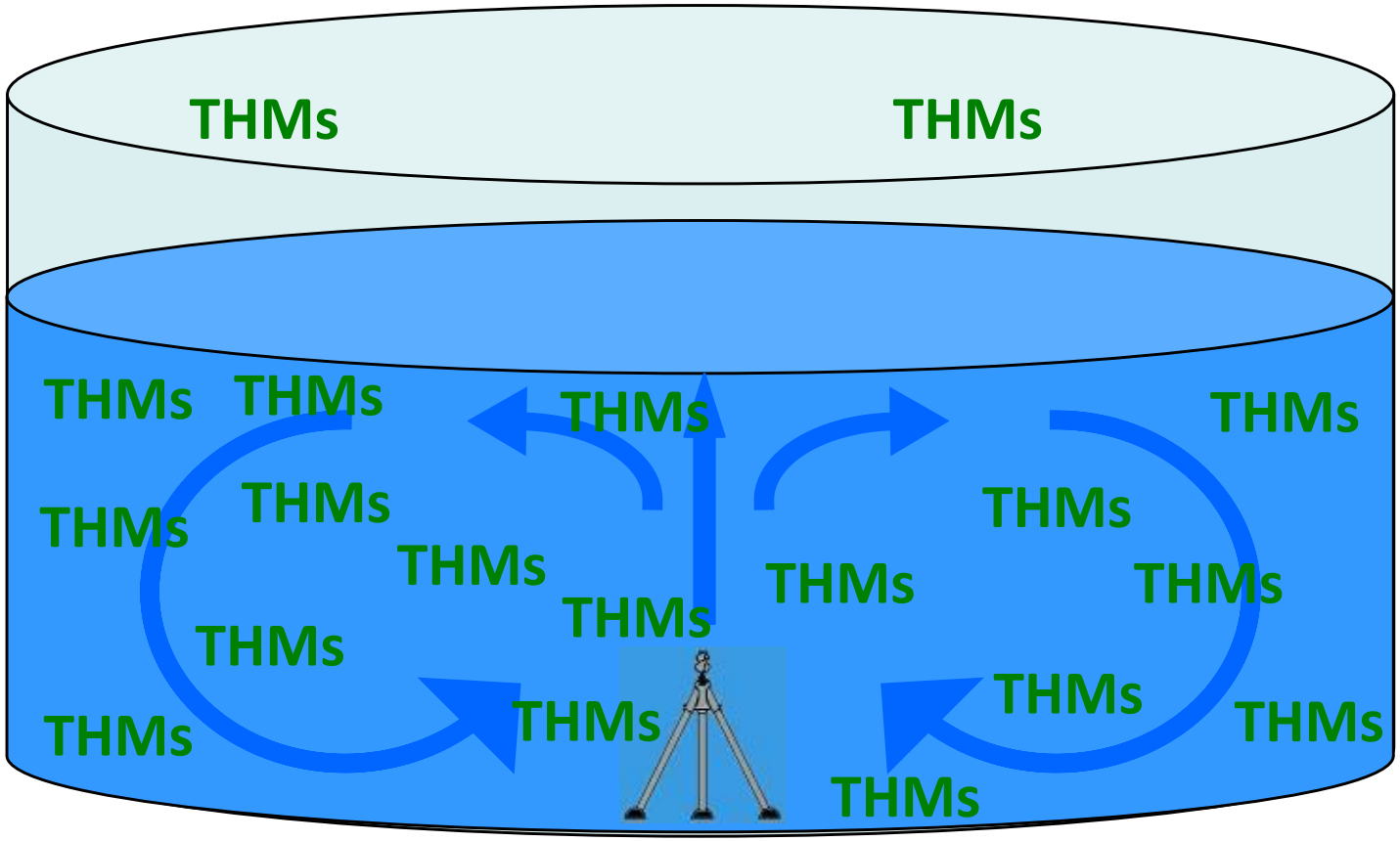
Chloroform is the most "volatile" (easiest to remove)

Bromoform is the least "volatile" (hardest to remove)

Some aeration happens all by itself…

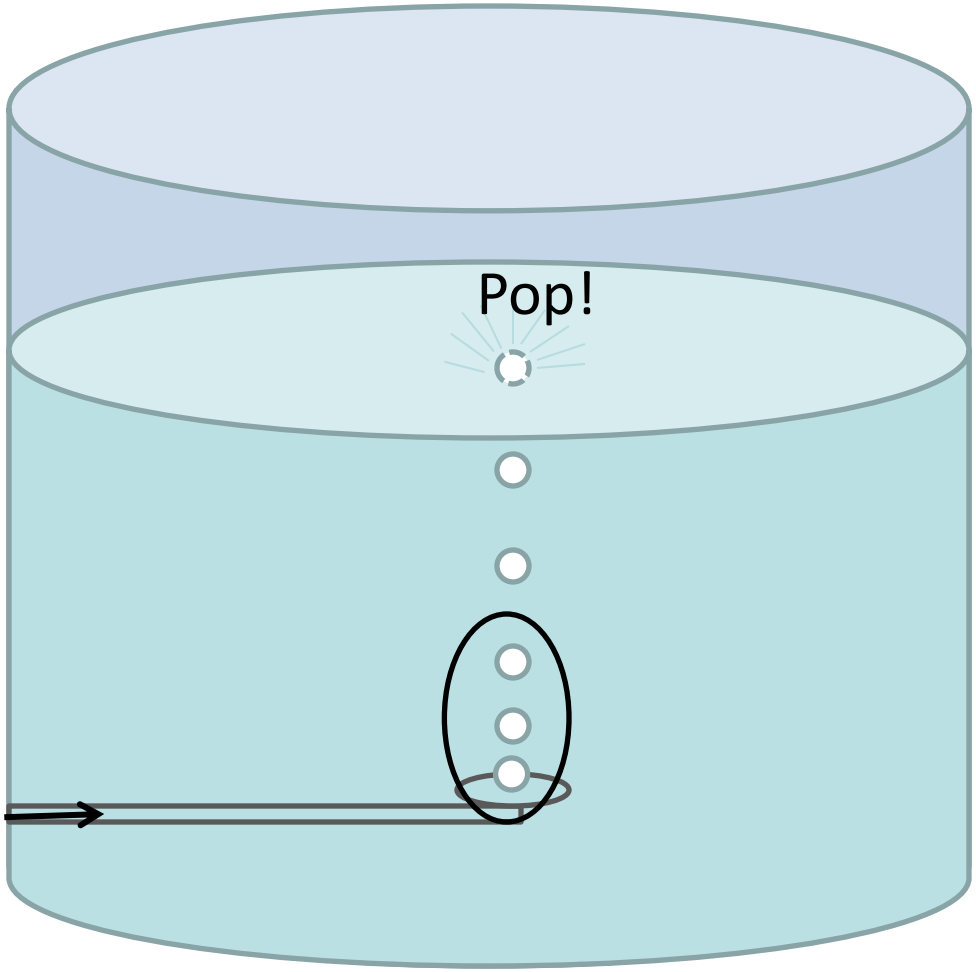


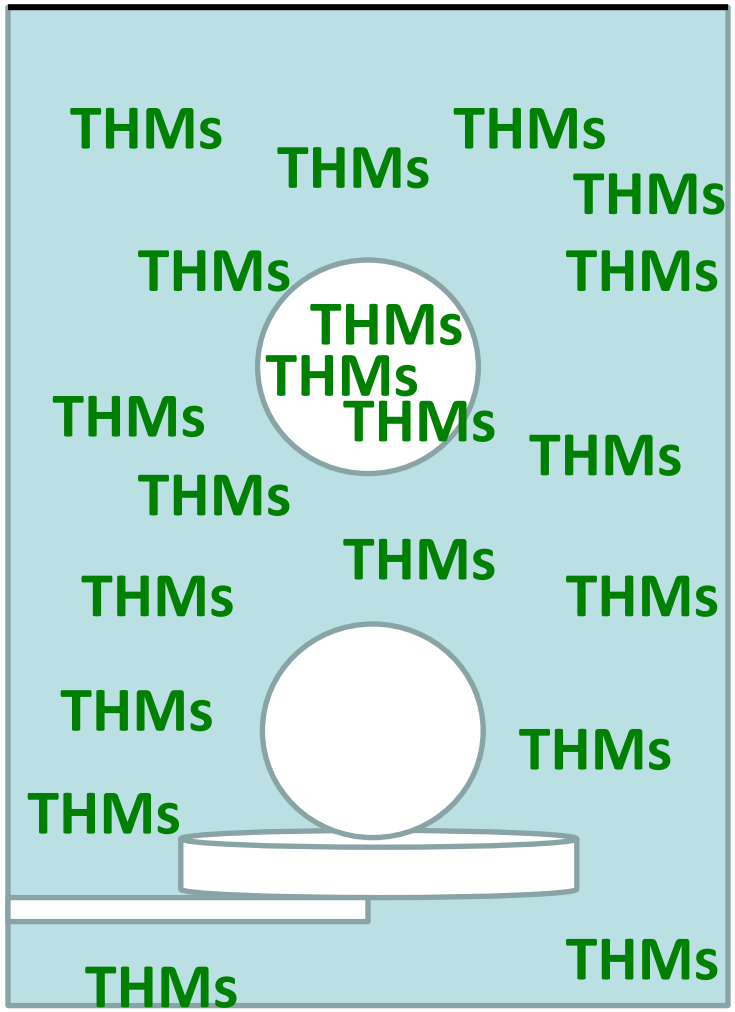
Mixing enhances aeration

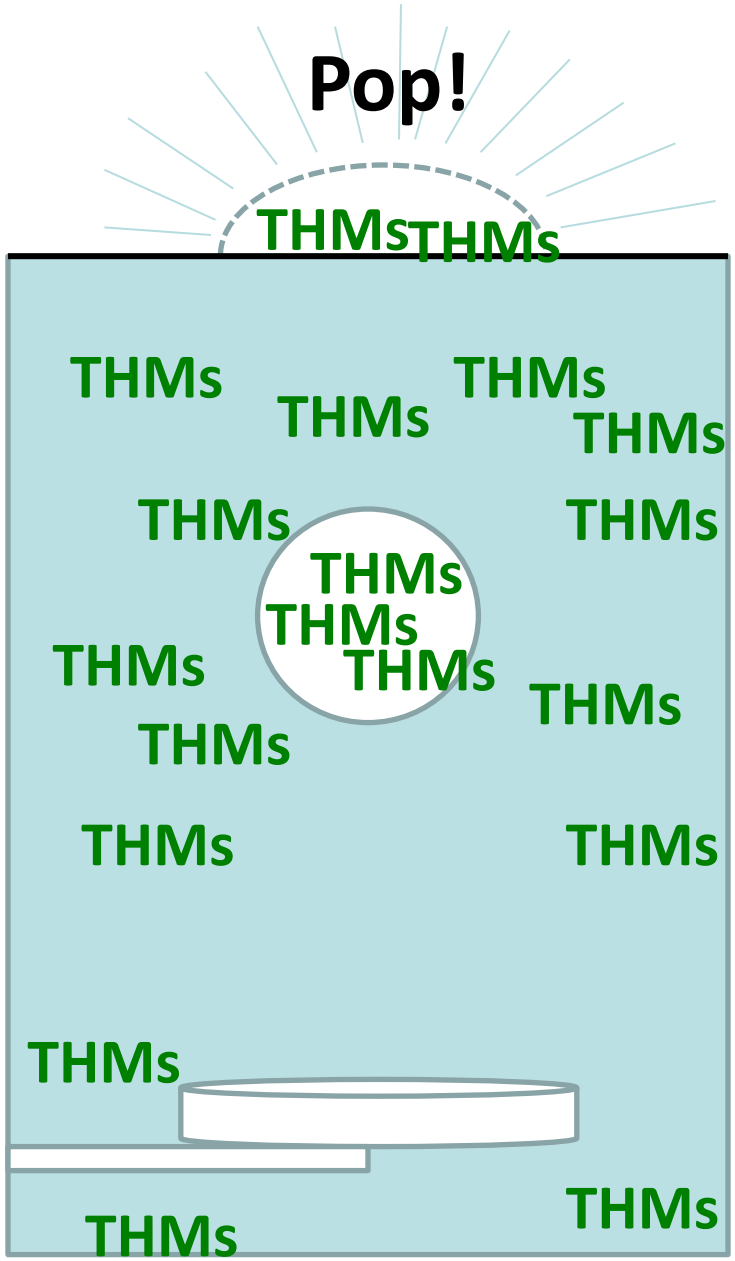


But you need <u>STRONG</u> mixing

Bubble aeration – How it works

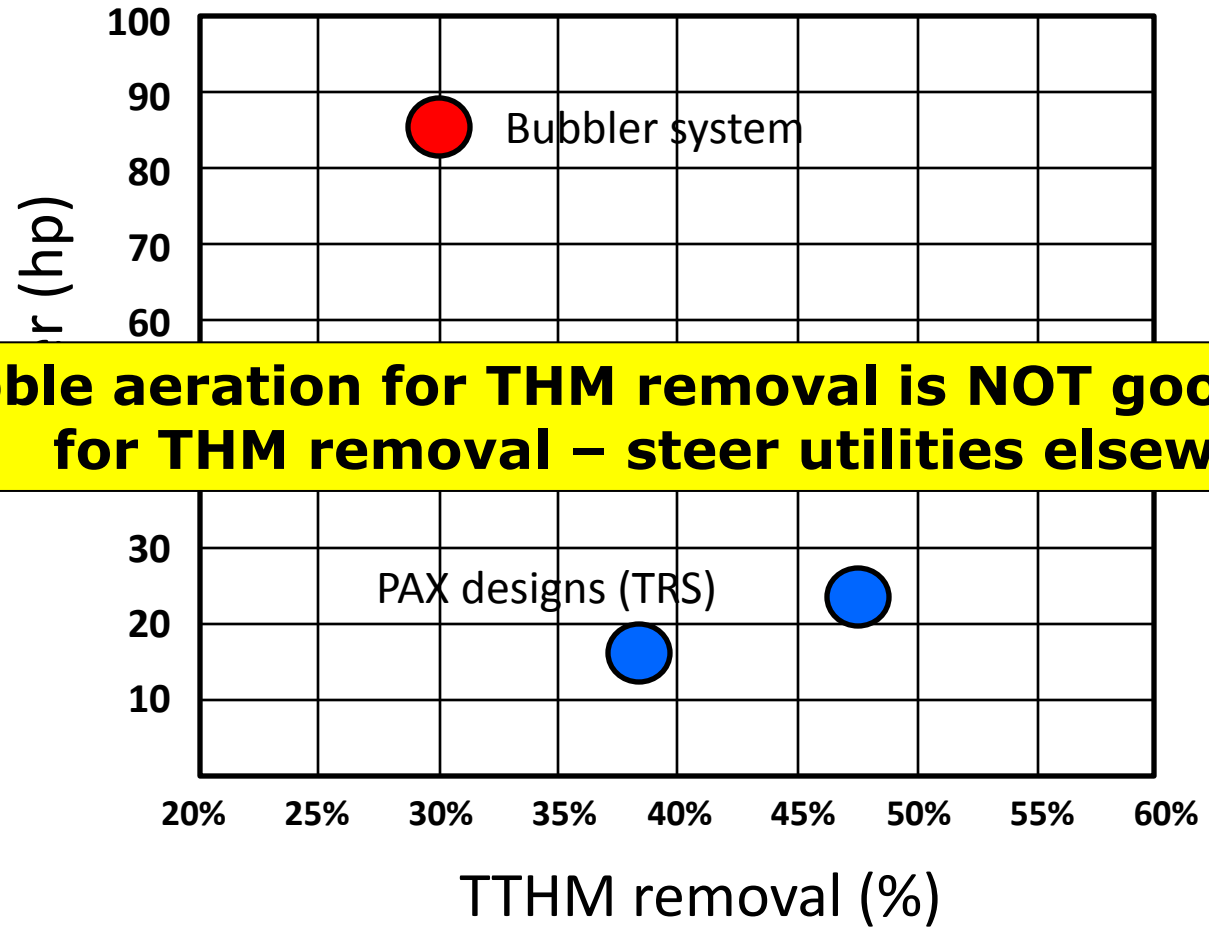






Bubbles pull THMs out of the water and deliver them to the surface

Bubbler versus PAX TRS (XX County, VA)



Bubble aeration for THM removal is NOT good practice for THM removal – steer utilities elsewhere

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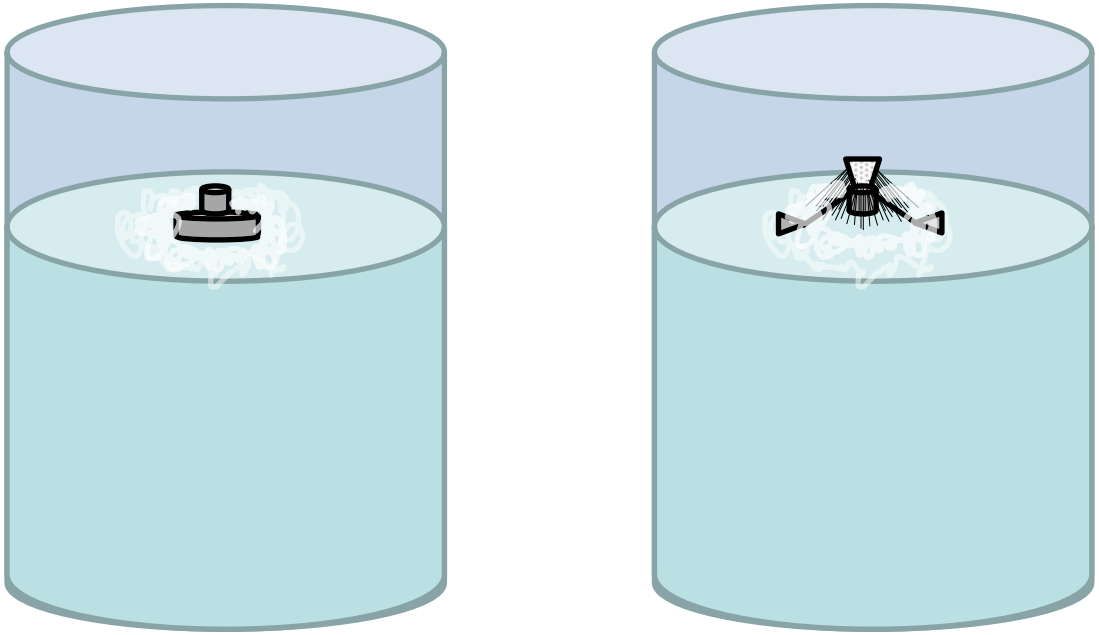
Surface Aeration



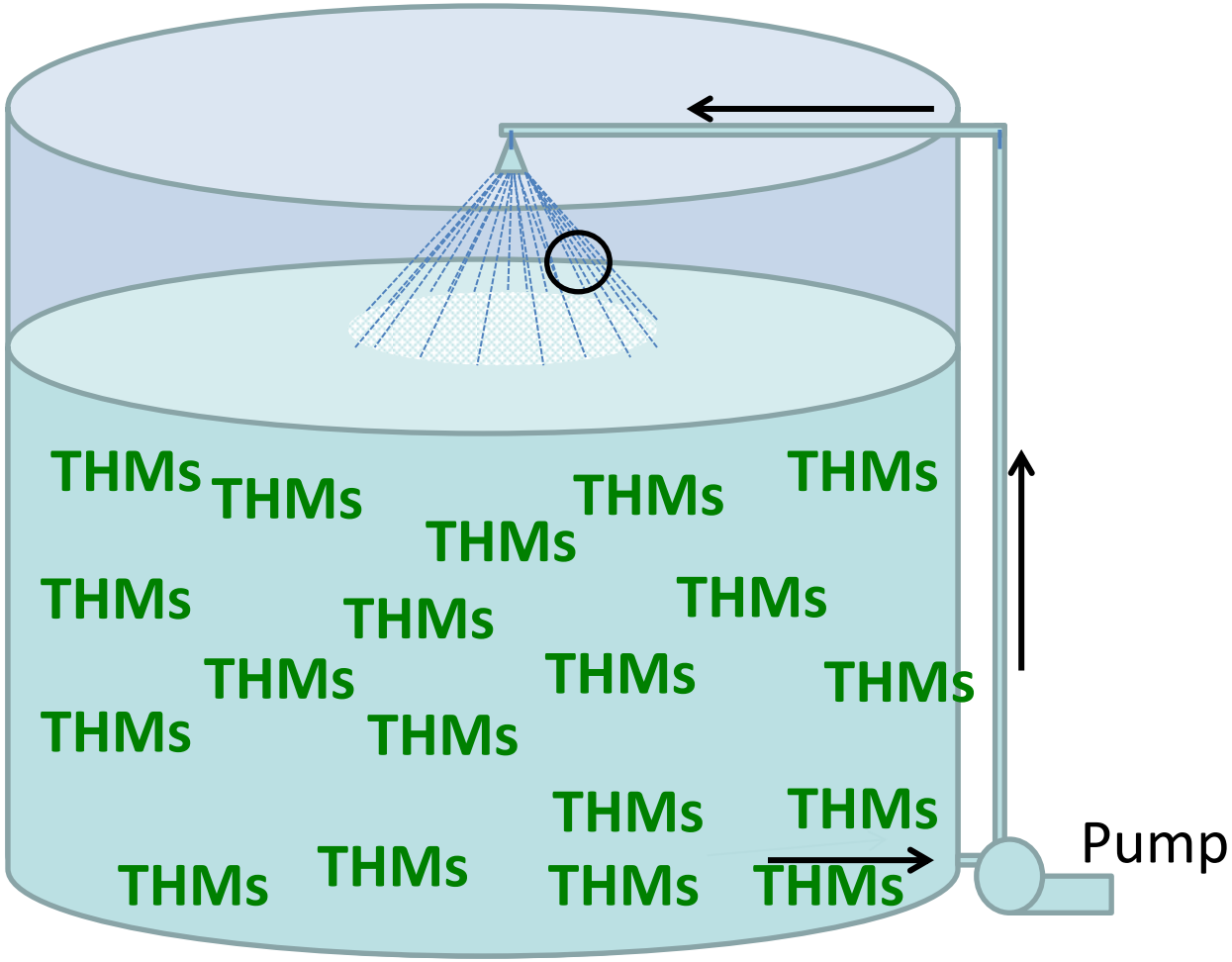
Advantages of Surface Aeration

- More energy efficient than bubblers
- Do not have to drain the tank to install
- Low profile (works with tight headspace)
- Good choice when water level is not changing

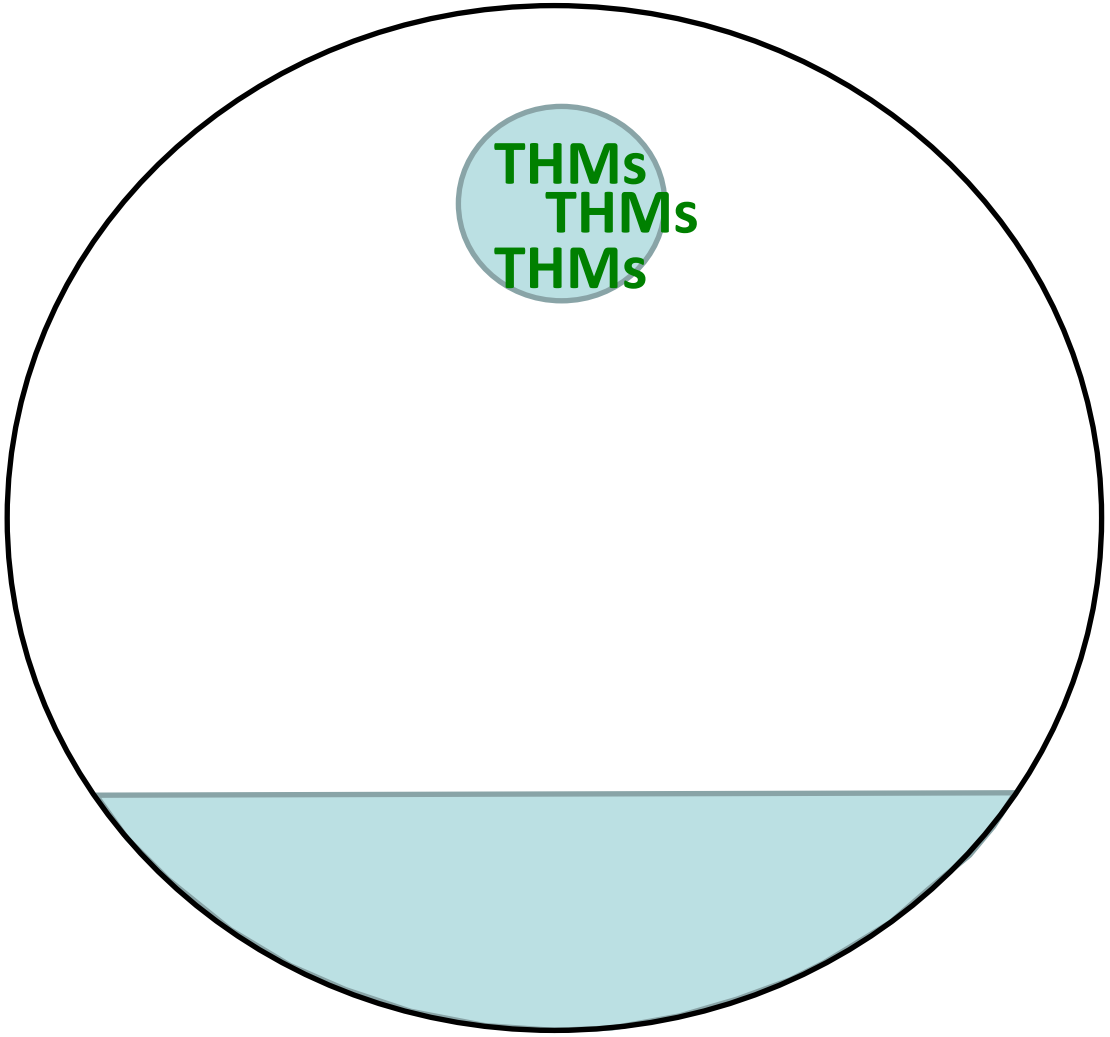
Disadvantages of Surface Aerators

- Less energy efficient than spray aeration
- Removal efficiency for bromoform is unknown
- Some systems have ejector nozzle with thousands of small holes
  - Clogging/maintenance concerns
- Requires guide rails in tanks where water level changes

Spray aeration



Evaporation from droplets

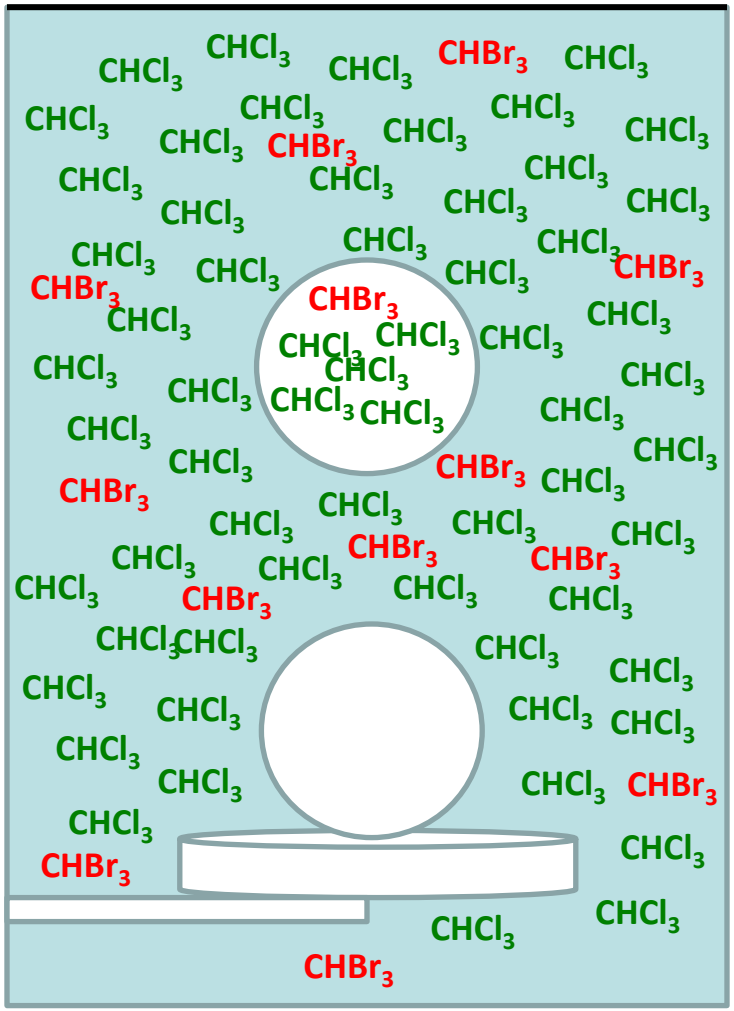


Advantages of spray aeration

- Energy efficient
- Mechanical equipment outside tank
- Easy install

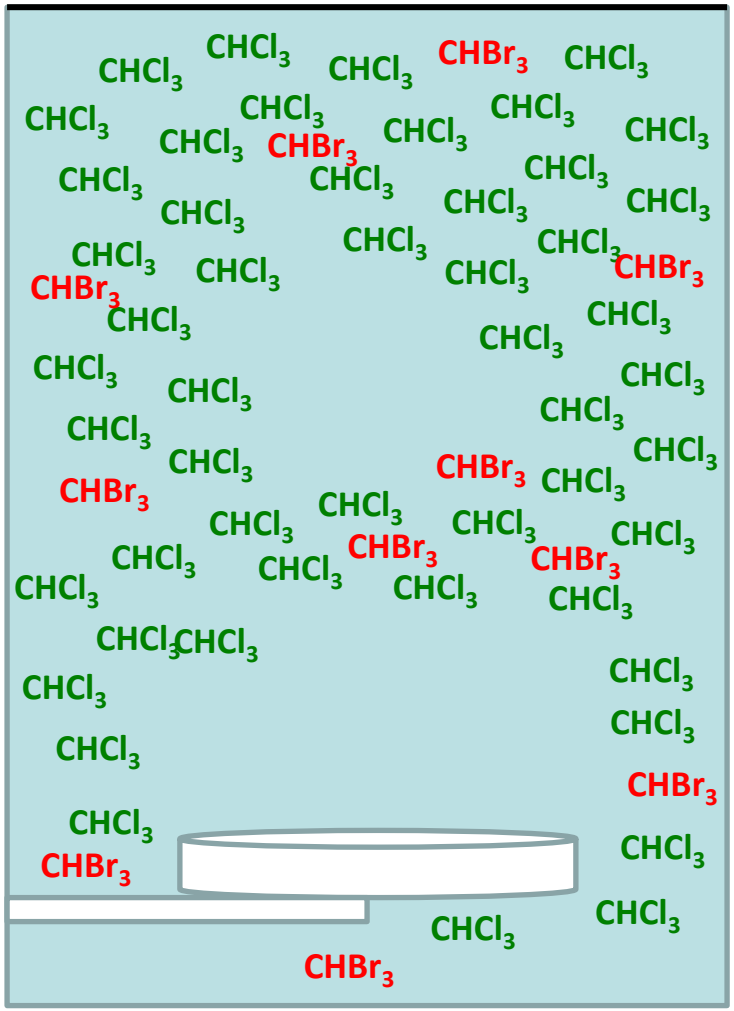
Bubble aeration = chemical equilibrium

- Rate of removal is controlled by <u>Henry's Law</u>
  - $CHCl_3$ Henry's Law constant = 7x $CHBr_3$



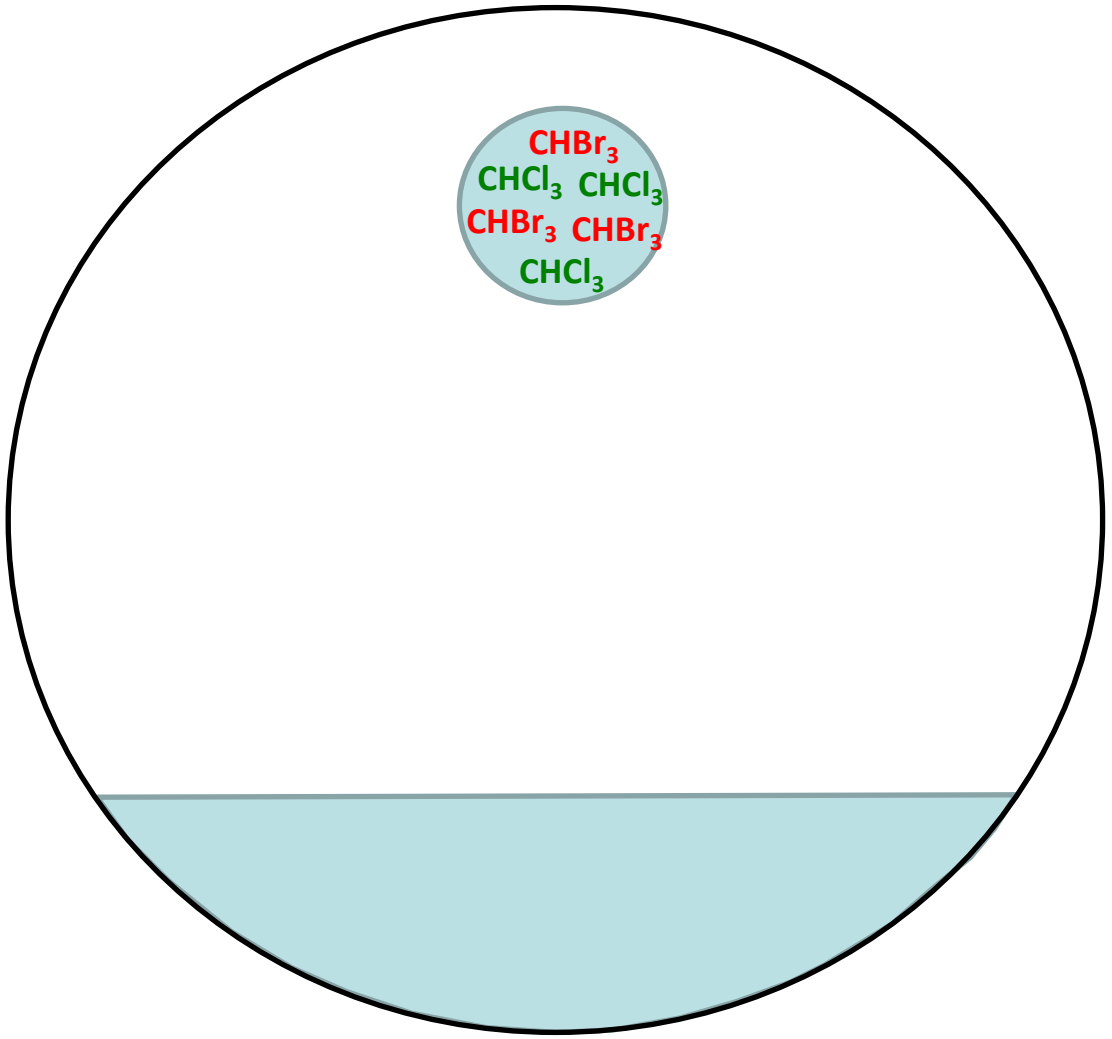
Chloroform is preferentially stripped Bromoform left behind

Bubble aeration is very inefficient for bromoform

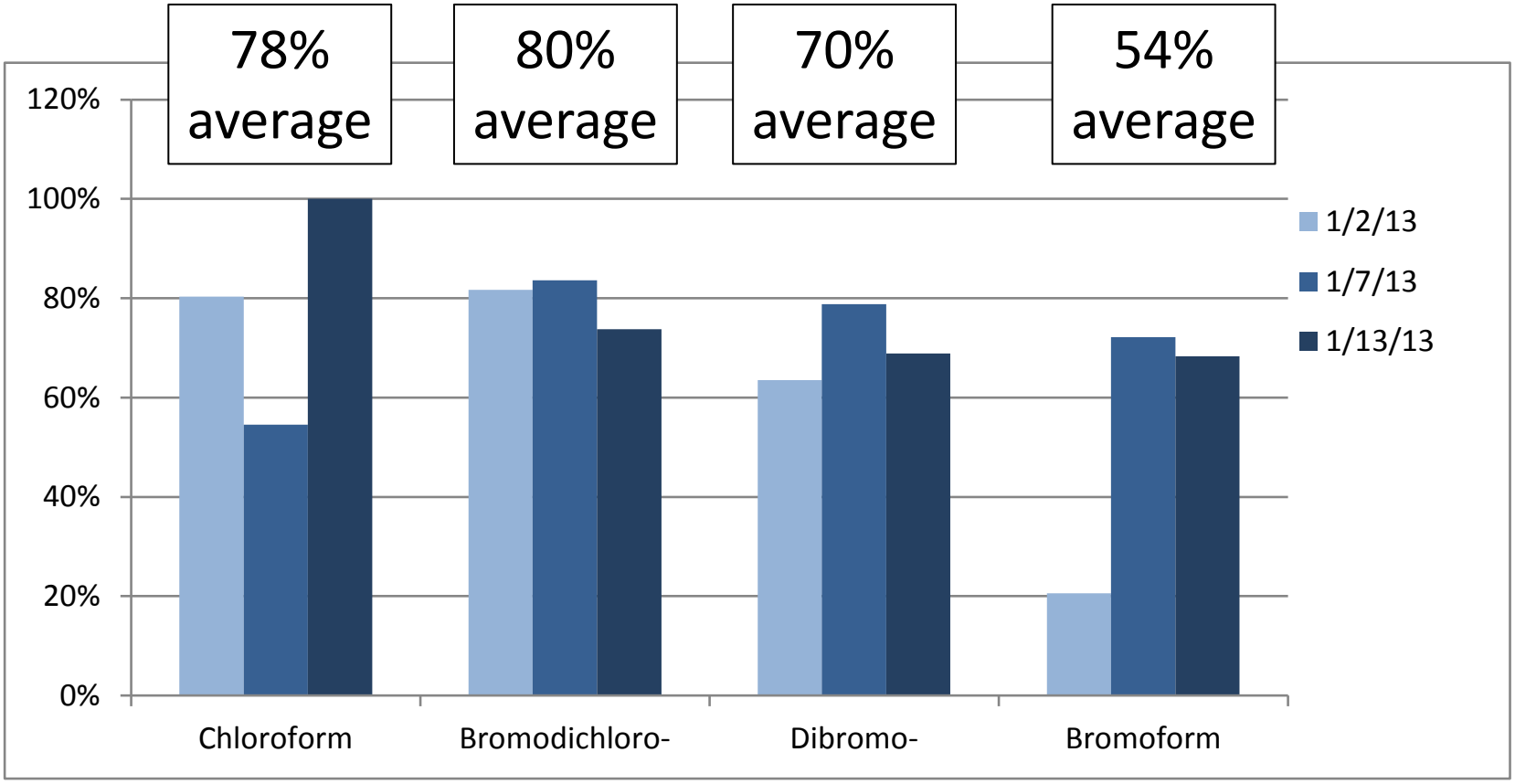


Droplets in air – no equilibrium established

Only difference in removal rates is due to differences in liquid-side diffusivity



% reduction by species – TRS

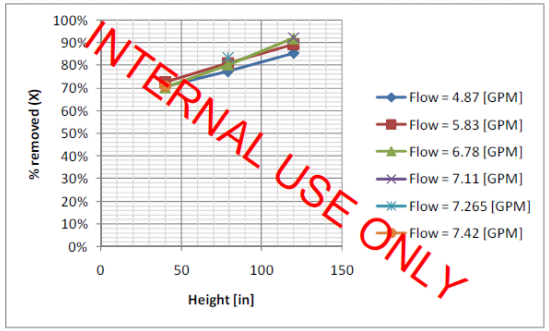


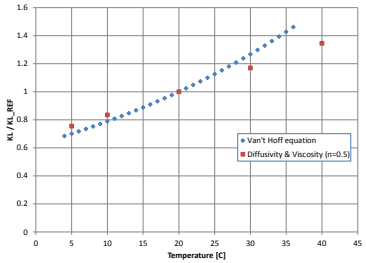
Disadvantages of spray aeration

- Very hard to predict results
  - Need quantitative models for spray and splash
  - Need full-scale experiments

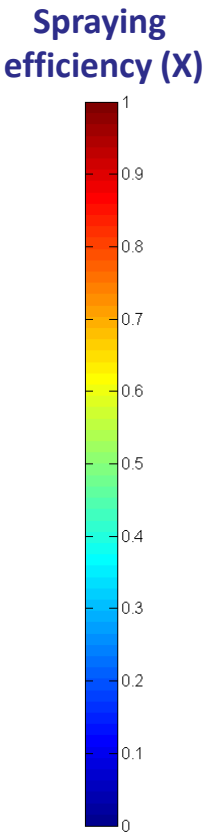
How did we develop the TRS?

- 2 years spent analyzing published and unpublished case studies on aeration for THM reduction
- 1.5 years spent measuring mass transfer coefficients for specific aeration technologies (lab and field studies)
- Optimized spray nozzle designs
- Trials (and tribulations!)



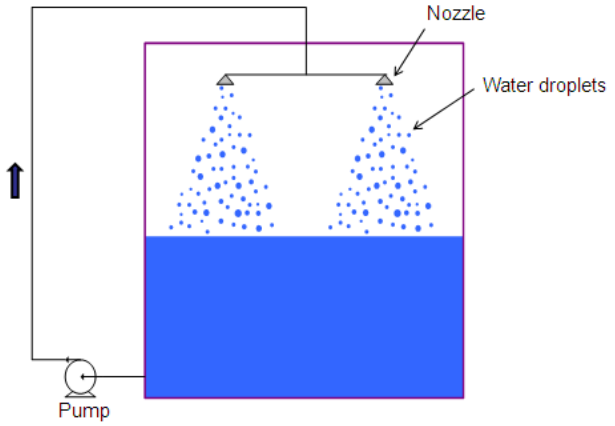


Spray Aeration: Droplet Size Dependent

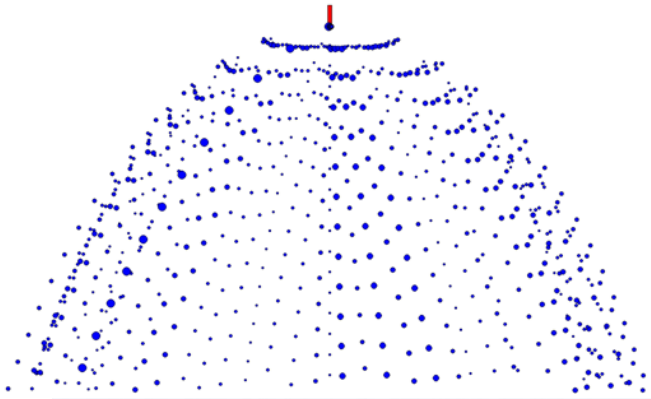


NEPTUNE™ Toolbox

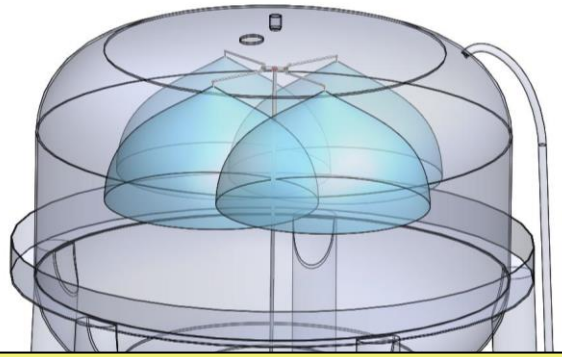
Water sprayed at the top of the tank to strip DBPs into air

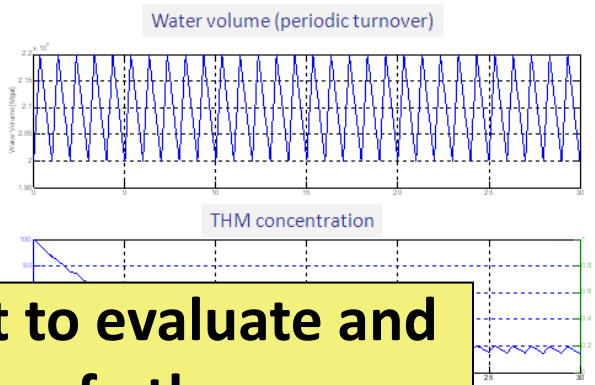


Spray efficiency model



Example of model output

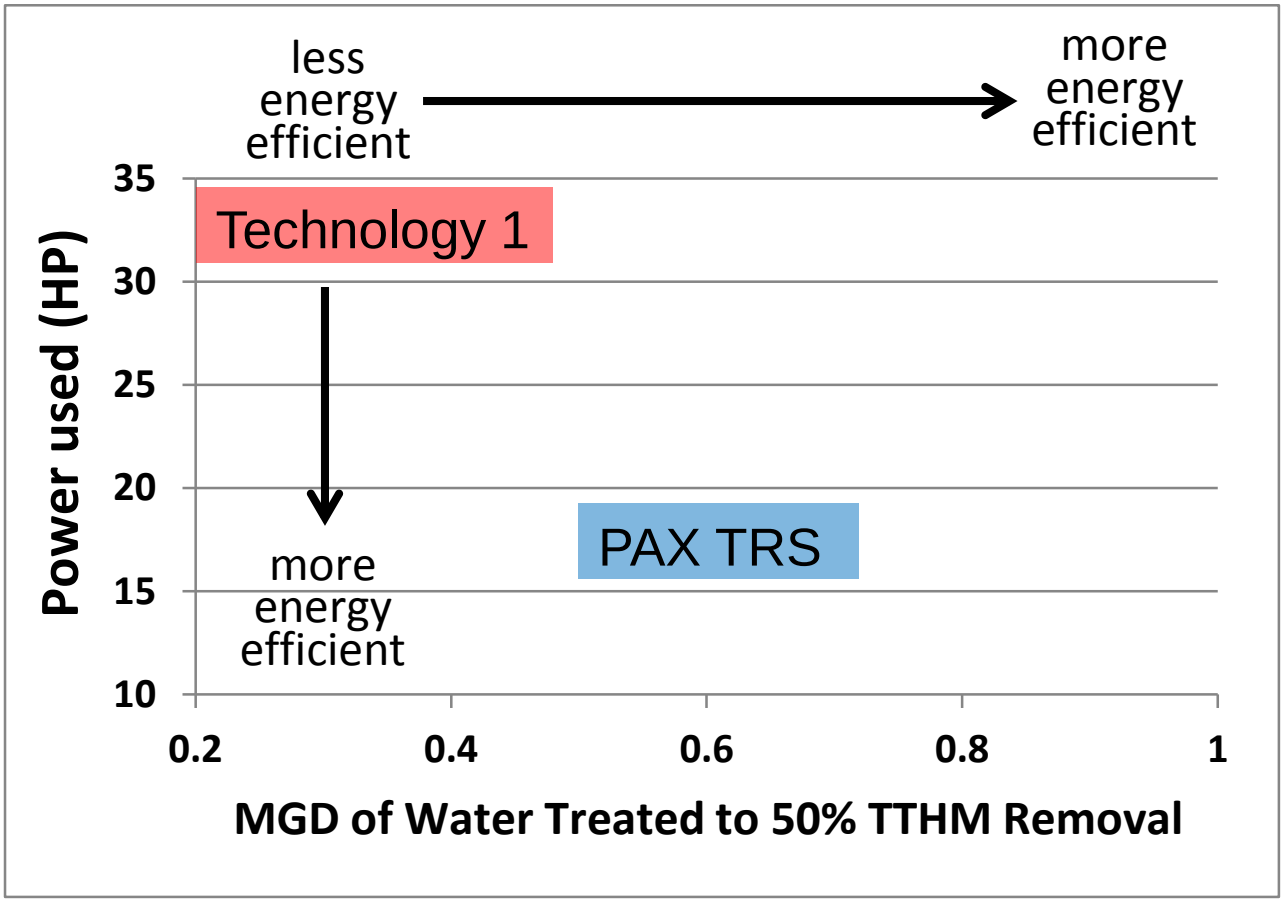


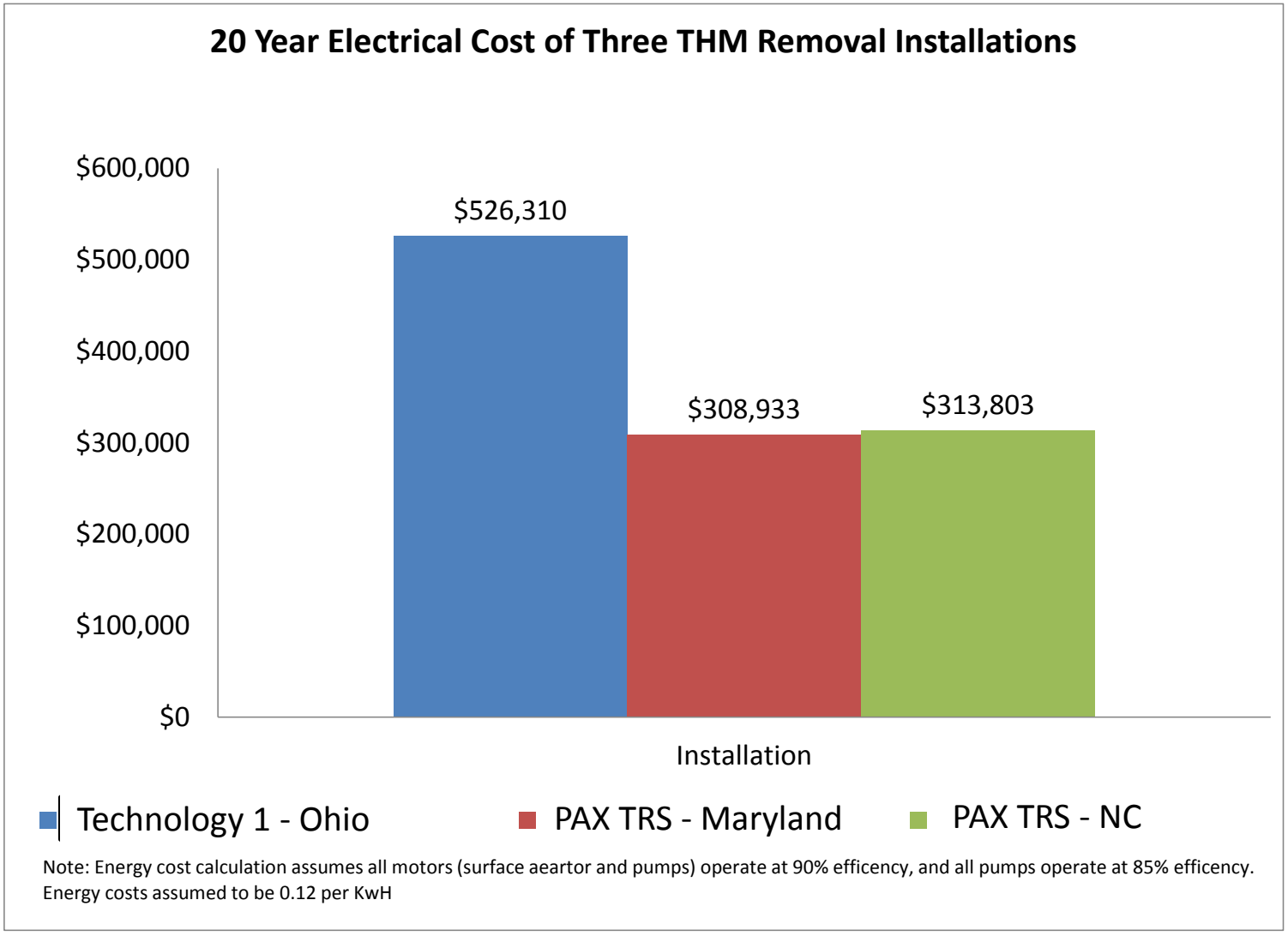


We can provide analytical support to evaluate and optimize the aeration designs of others, and we can design for new tanks

Energy comparison between other spray aeration technologies and PAX TRS

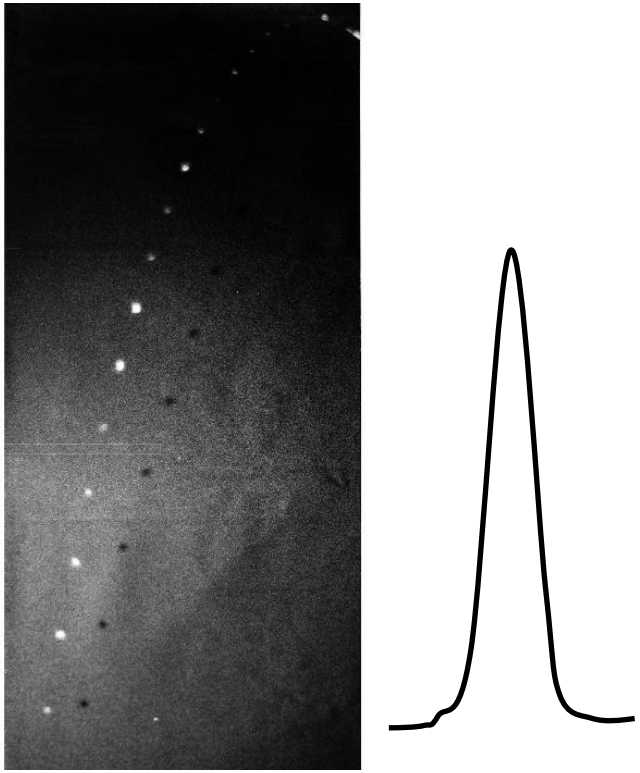
- **Case study 1: Technology 1 (Ohio clearwell 0.3 MG)**
  - Equipment: Two 15 hp “spray aerators” + 2 HP fans
  - Daily turnover: 475,000 GPD
  - Energy used: 32 hp
  - **THM removal measured: 55%**
- **Case study 2: PAX (Maryland storage tank 8.0 MG)**
  - Equipment: Two 7.5 hp pumps, PAX nozzles, one PAX mixer, one PAX PowerVent
  - Daily turnover: 775,000 GPD
  - Energy used: 18 hp
  - **THM removal measured: 53%**
- **Case study 3: PAX (North Carolina clearwell 0.5 MG)**
  - Equipment: One 15 hp pump, PAX nozzles, one PAX mixer, one PAX PowerVent
  - Daily turnover: 750,000 GPD
  - Energy used: 17 hp
  - **THM removal measured: 50%**



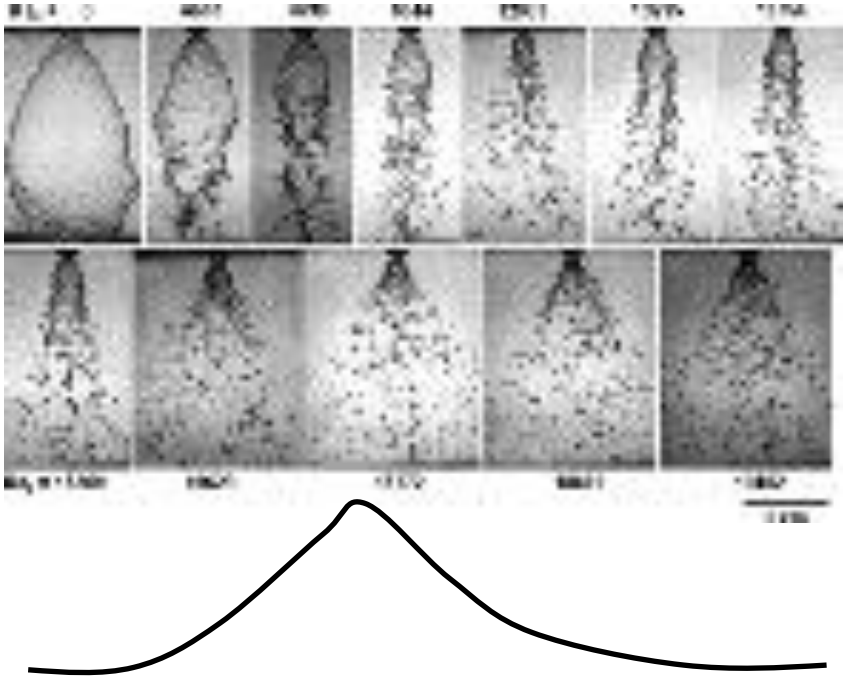


How can two different spray aeration systems have such different energy efficiencies?

Oriface sprayers



Break-up sprayers



TRS Case Studies

Ryan Ranch tank (Monterey, CA)

- Ryan Ranch Tank: 0.5MG, 72’ dia., 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

- Proposed sprayer aeration system ($350K)
- Limited power at tank

The TRS goals and design

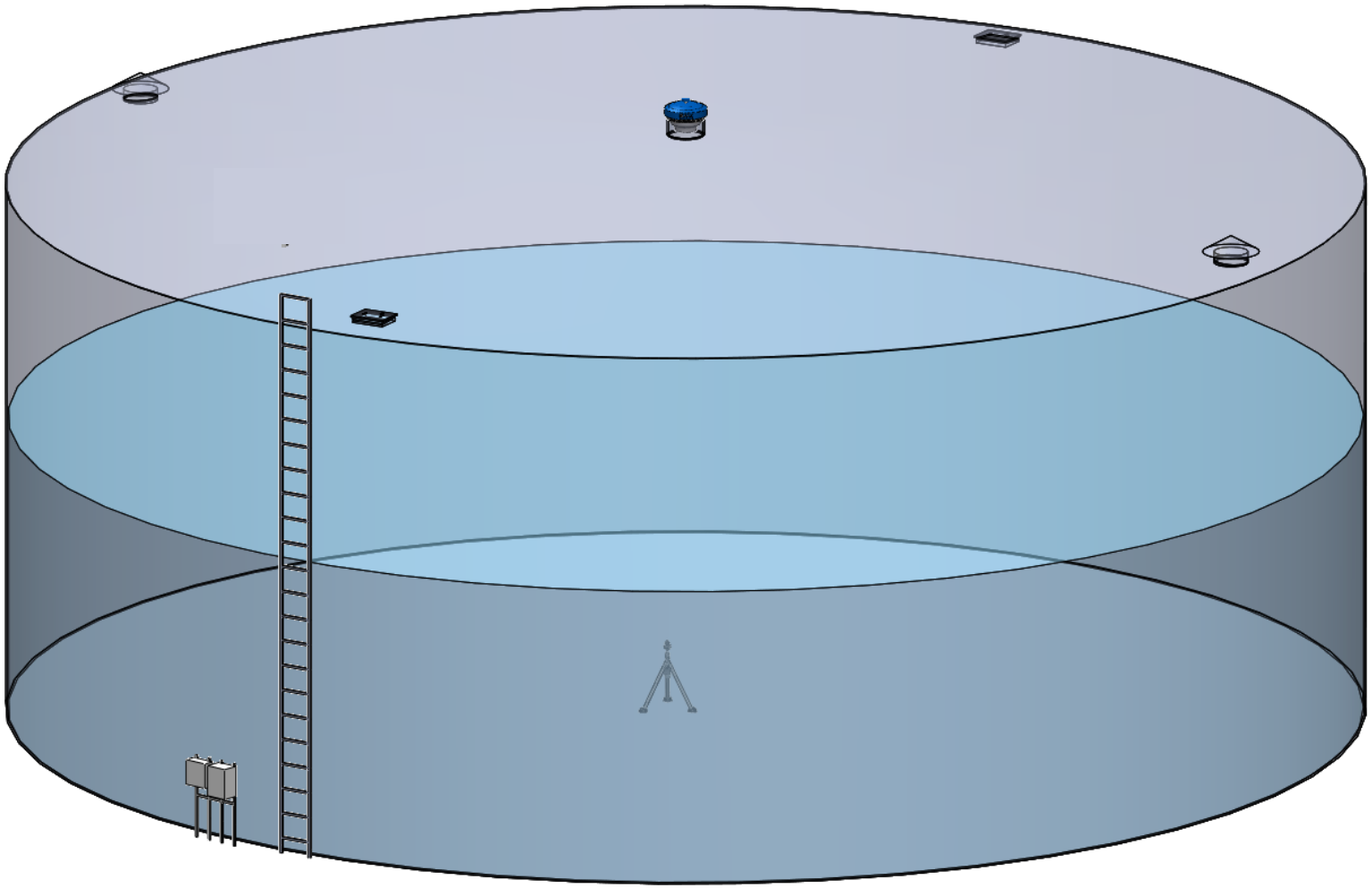
Goals

- Lower Cl demand
  - Eliminate stratification
  - Clean tank
- Remove THMs
  - Aeration
  - Goal: 60% reduction
- Use as little power as possible

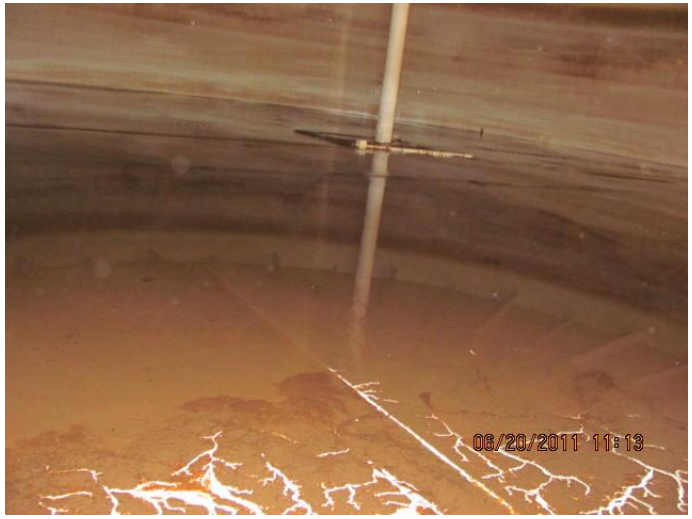
Design

- Wash-out
- Chemical clean
- 1 PWM-400 mixer
- 1 PAX Powervent fan

Design for Ryan Ranch TRS



TRS installation: Chemical cleaning

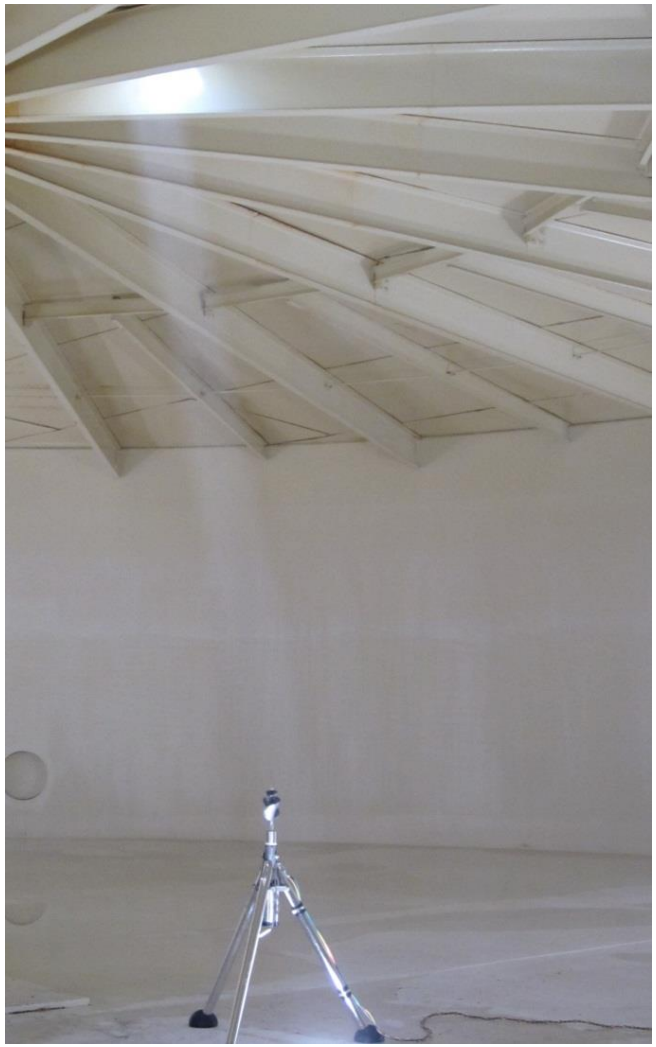


TRS Installation: Interior coatings repair

TRS Installation: PAX PowerVent™ Installation

TRS Installation: Mixer Installation

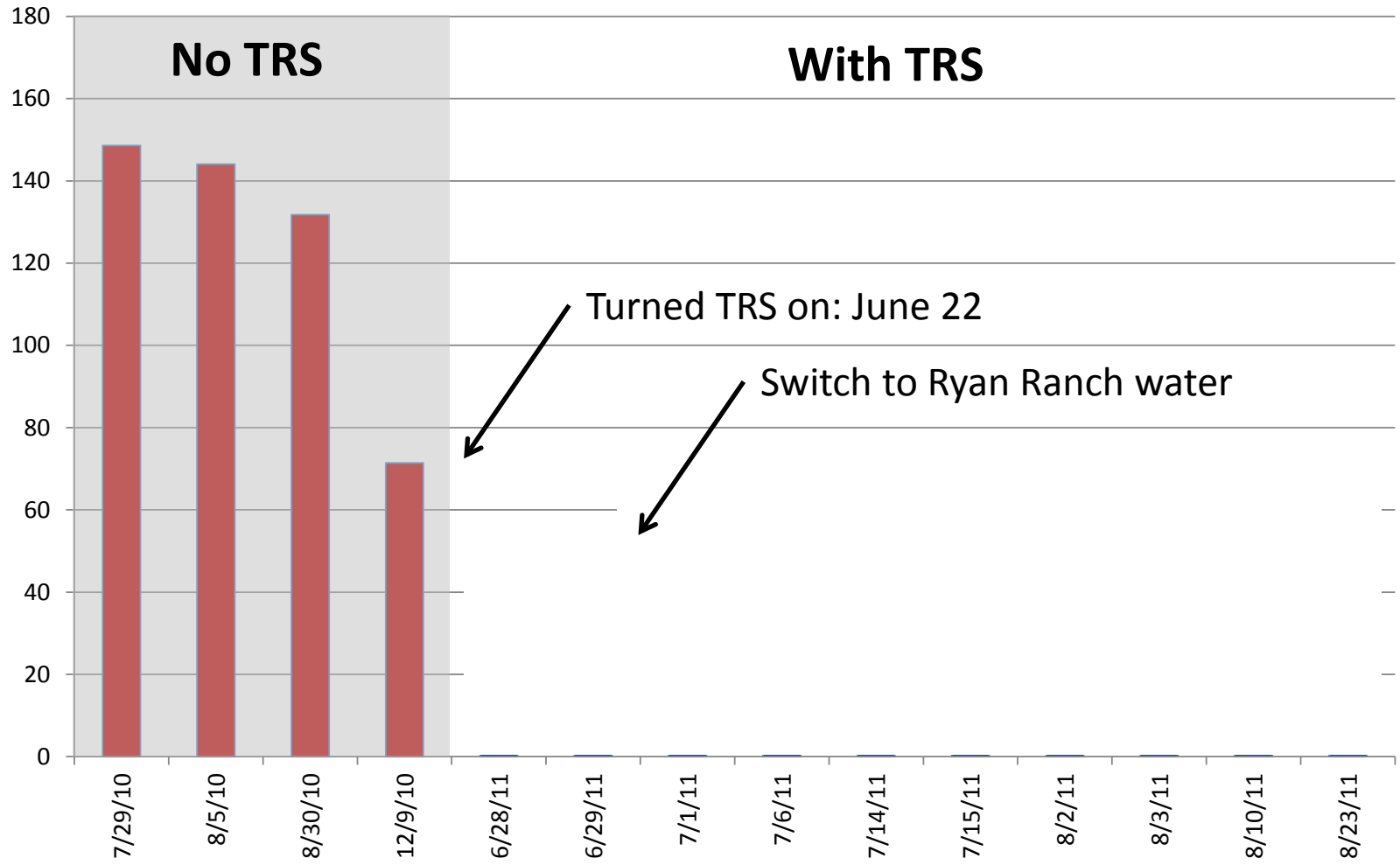
Initial results of Q3 compliance test

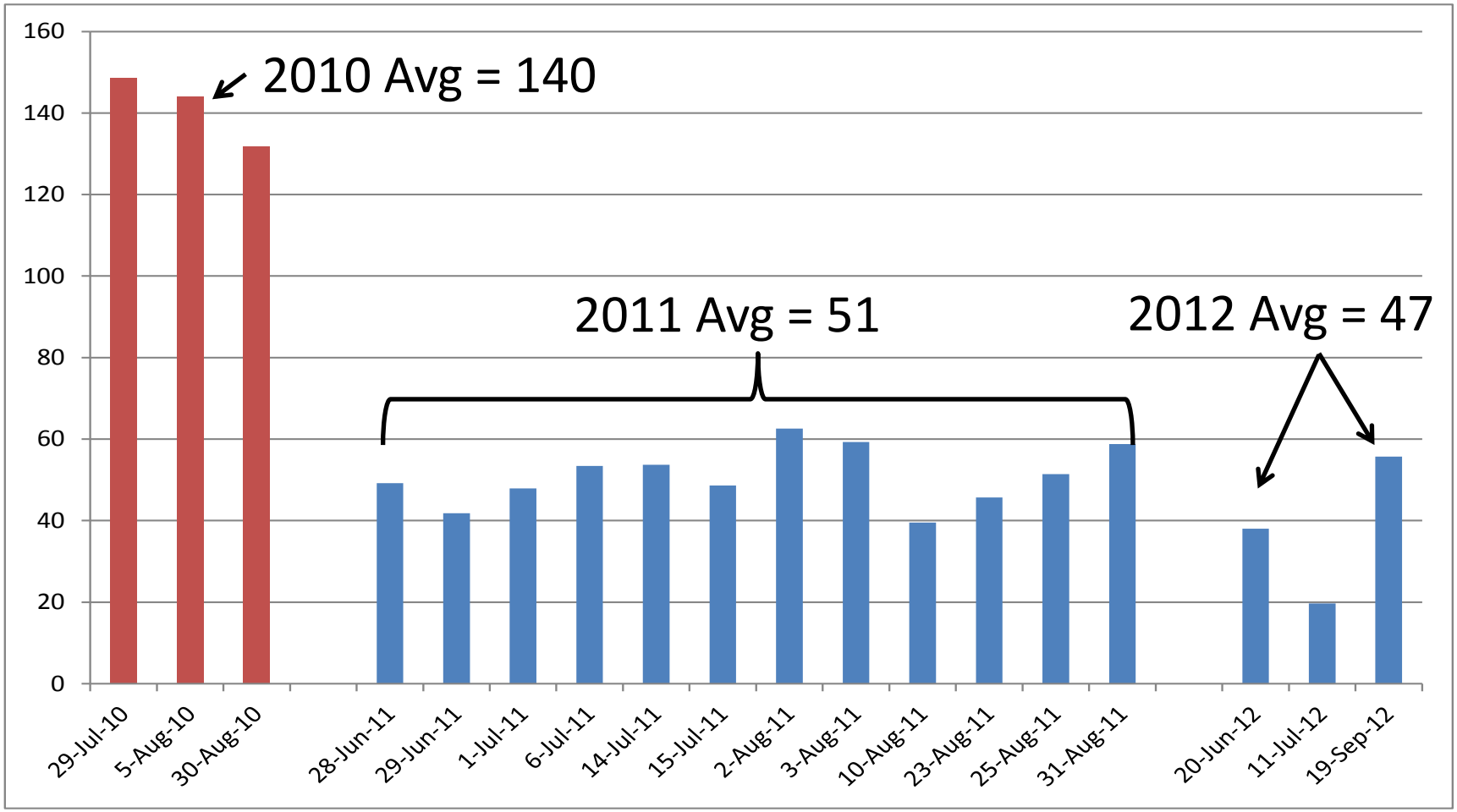


Post-TRS

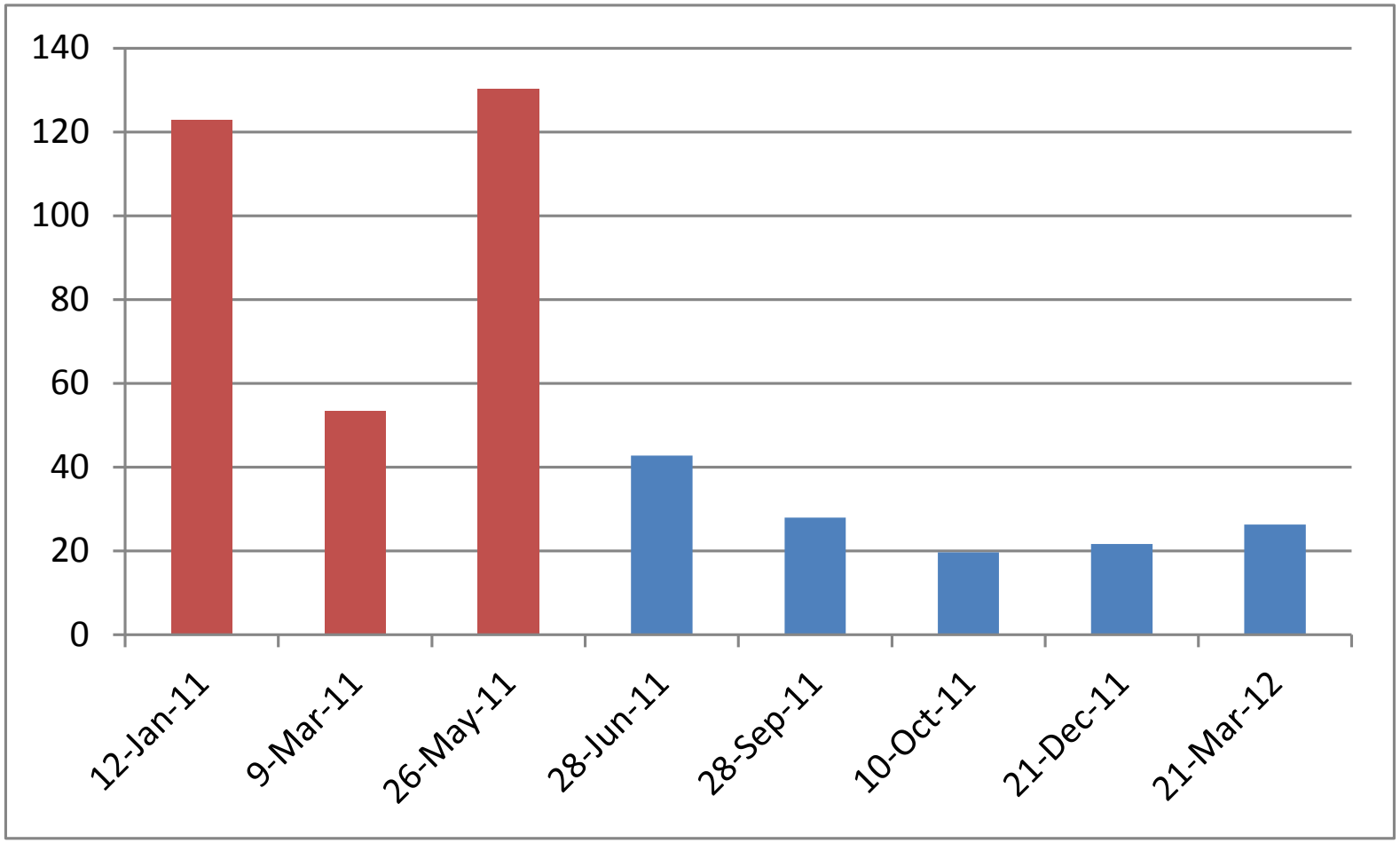
Q3 Sample result = 49.2 µg/L

RAA = 79.3 µg/L





Upper Ragsdale (Compliance point)



Lowering THM Levels and Achieving Stage 2 DBP Rule Compliance with In-Tank Aeration

By Peter S. Fiske, Ph.D., and Leslie Jordan

Across California and Nevada, implementation of the Stage 2 Disinfectants and Disinfection By-product Rule is spurring utilities to explore a range of strategies for improving water quality in their water systems. Many utilities are investigating ways of lowering total organic carbon (TOC) in their water or altering treatment plant processes to reduce the production of disinfection byproducts (DBPs). Unfortunately, many of these treatment plant changes are large capital projects that will take several years to complete.

The most common DBP, trihalomethanes or THMs, is a function of both raw water quality AND disinfectant levels and water age. Thus, some utilities are also examining ways in which operational and technological changes in their distribution system can lower DBP levels. In many cases, high THM levels are present in only one part of a water distribution system, most commonly where water age is the highest or source water quality is a challenge. By deploying new technologies in distribution system water storage tanks, a few utilities have discovered that THM levels can be brought under control.

Monterey, California, is a seaside town that enjoys cool weather, picturesque beaches and, for the most part, excellent water quality. However, one part of the system, the Ryan Ranch Business Park, faced water quality challenges. Ryan Ranch was fed by three wells separate from the rest of the Monterey system, and treated water was stored in a single 500,000 gallon above-ground, steel storage tank. While raw water TOC levels were low, the well water was known to contain elevated levels of bromide.

Beginning in 2010, TTHM levels spiked, and the running annual average for the Ryan Ranch system rose dramatically (Figure 1). The dominant THM species was bromoform. After accumulating three quarters of elevated levels, water quality managers calculated that they needed to achieve a TTHM level of less than 50 ppb for the June 2011 measurement for the locational running annual average (LRAA) to remain in compliance. Historical estimates suggested that without a major intervention, actual TTHM levels at that time would be around 140 ppb.

The precise causes of the dramatic increase in TTHMs in the Ryan Ranch tank were uncertain, but several factors likely contributed to the problem:

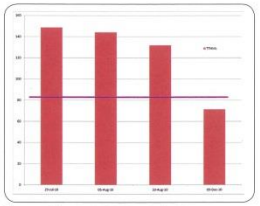


Figure 1. Historic TTHM levels (ppb) per quarter at Ryan Ranch. Locational running annual averages were expected to exceed the MCL in Q2 2011.

The combination of high temperatures and low turnover likely led to thermal stratification during some of the year. Thermal stratification leads to high water age and high rates of residual consumption, both of which can elevate THM levels.

The use of source water high in bromine likely stimulated the formation of brominated THM species such as bromoform.

The tank had been periodically washed out, but it had not been chemically cleaned to

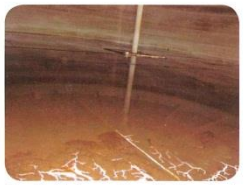


Figure 2a. Interior conditions of the Ryan Ranch tank prior to TRS.

Figure 2b. Locations where the interior coatings had failed in the Ryan Ranch tank (these were repaired).

Figure 2c. Application of the chemical cleaning agent to remove organic and inorganic deposits on interior surfaces.

THM Levels, Continued from page 21

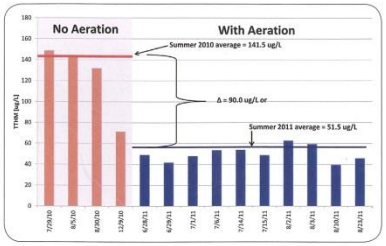


Figure 3. TTHM levels at the Ryan Ranch tank in 2010 before installation of the TRS (red) and 2011 after installation of the TRS (blue).

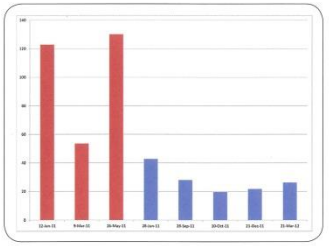


Figure 4. TTHM levels at the Upper Ragsdale Court sample location before installation of the TRS (red) and after (blue).

cleaning all likely worked together to lower disinfectant consumption, lower temperatures and physically remove THMs formed in the tank. By applying an integrated approach to THM reduction, operators at Monterey were able to achieve a successful result.

Peter S. Fiske, CEO, Pax Water Technologies, received his Ph.D. in Geological and Environmental Sciences from Stanford University and is the author of over 20 peer-reviewed articles. He has technical expertise in the fields of chemistry, fluid mechanics and physics.

Leslie Jordan, Water Quality/Environmental Compliance Superintendent, California American Water, Monterey, has 26 years of experience in the water industry, and has had operations and management roles in water quality and environmental compliance.

Source Magazine
(CA/NV AWWA Magazine)
Winter, 2013 (V. 27, no. 1)
p. 20-23

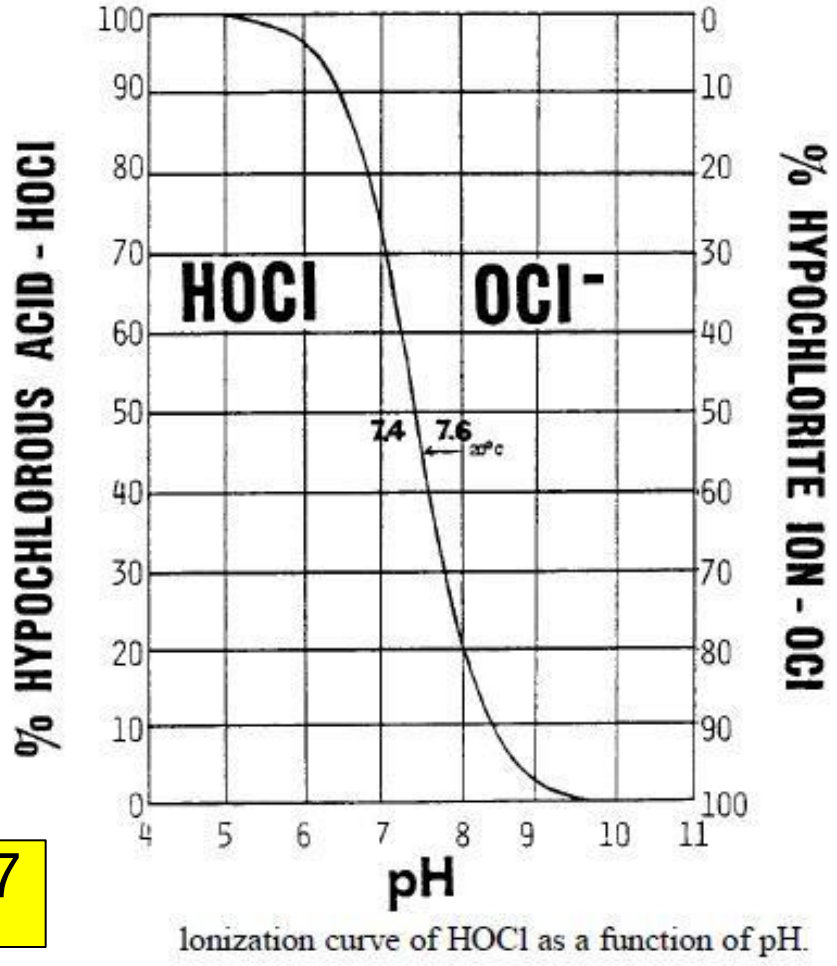
How do various TRS components contribute?

- 1 MG concrete tank
- Split into two identical cells
- AMS-100 On-line THM analyzer

Collaborators: Ramon Ariño Tarrago
Oriol Mas Alcazar

Chlorine loss? Depends on pH

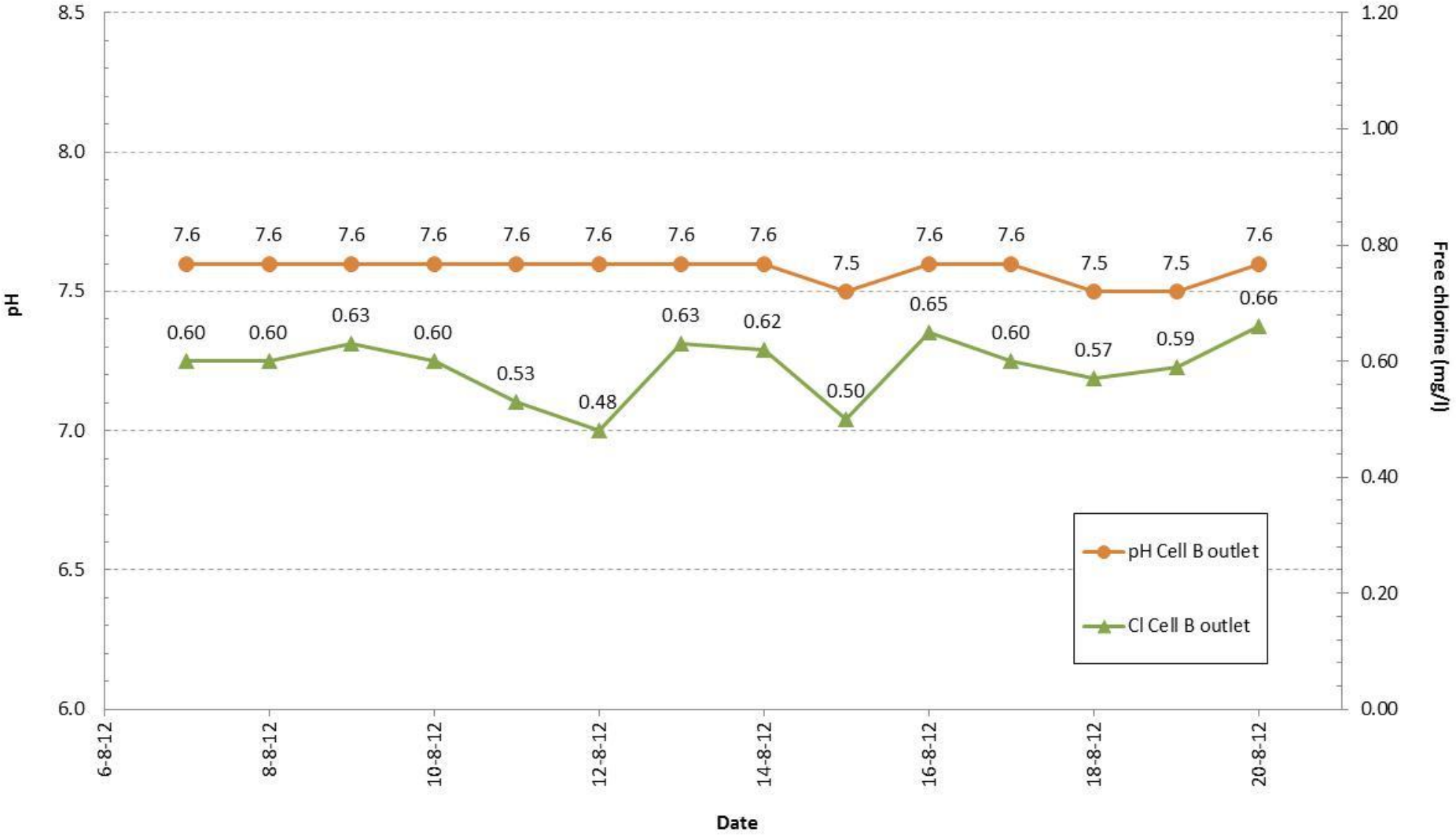
- HOCl is volatile: dominant species @ pH < 7
- OCl^- is an ion and non-volatile: dominant species @ pH > 7



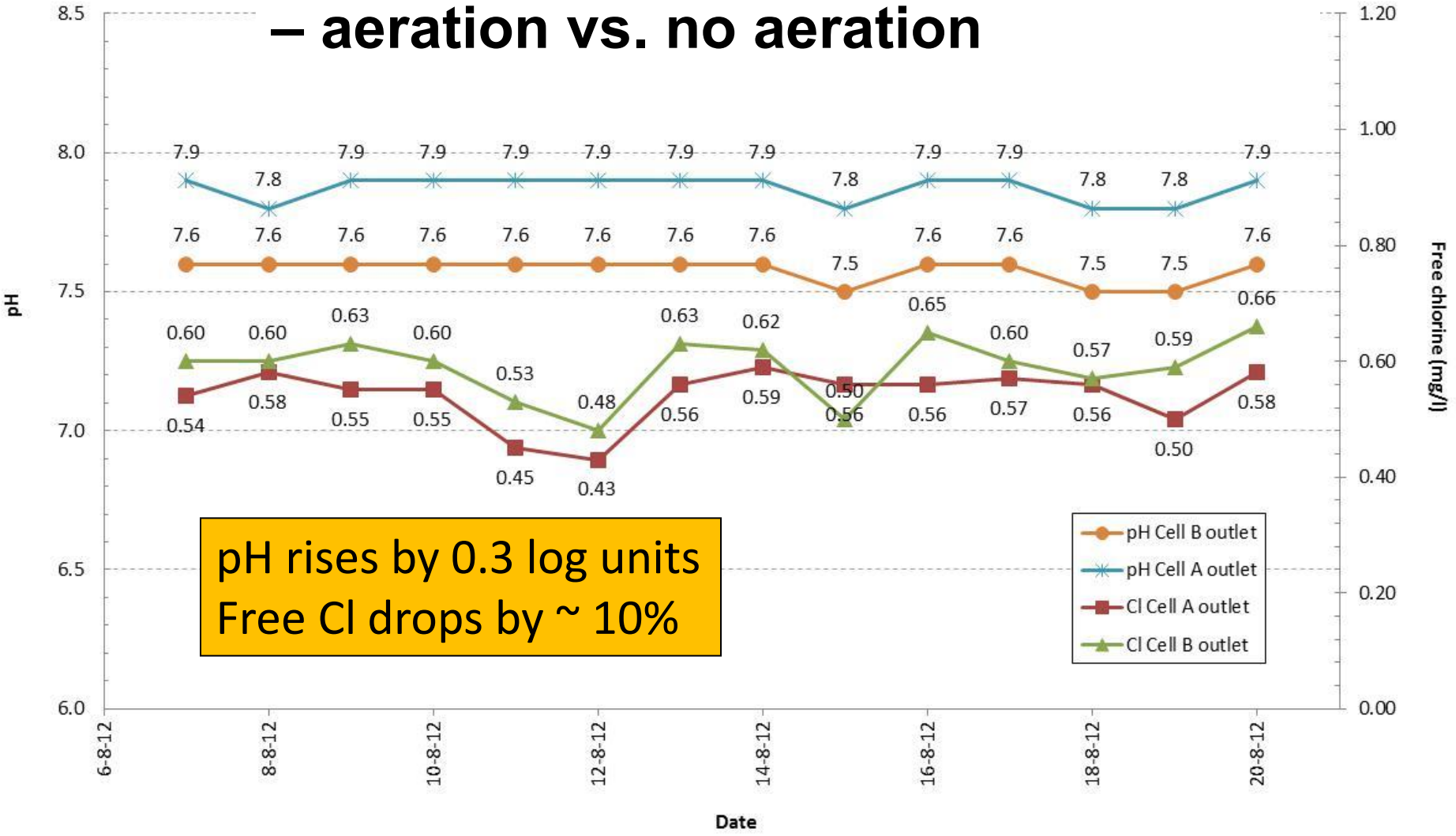
Ionization curve of HOCl as a function of pH.

Chlorine loss low(er) at pH > 7

pH and Free Chlorine – no aeration

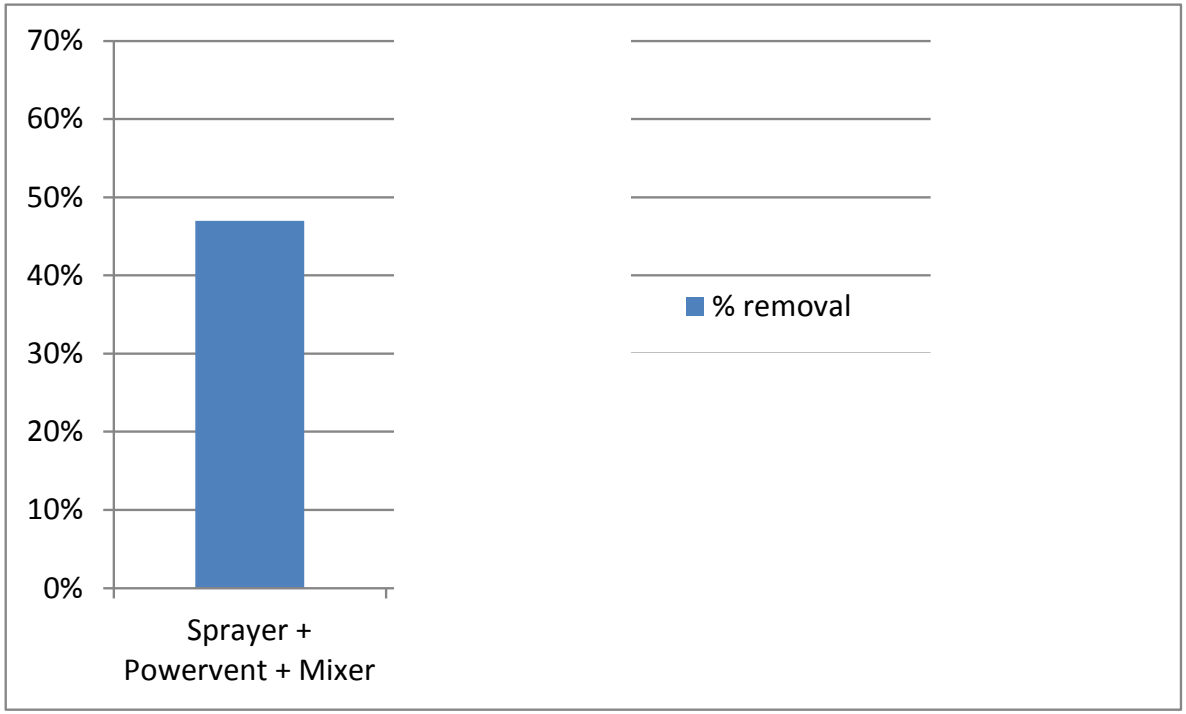


pH and Free Chlorine – aeration vs. no aeration



pH rises by 0.3 log units
Free Cl drops by ~ 10%

How do the sub-components of the TRS contribute to overall THM reduction?



Aigües de Barcelona
Department of Water Quality

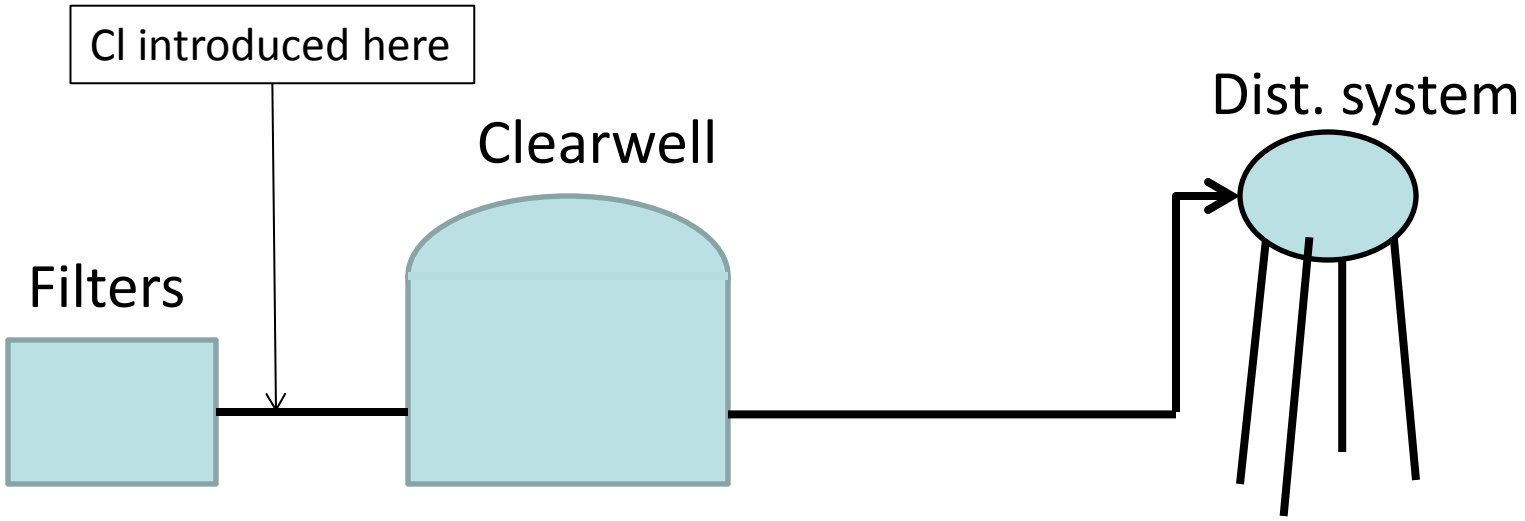
PAX Mixer + PAX PowerVent = THM reduction

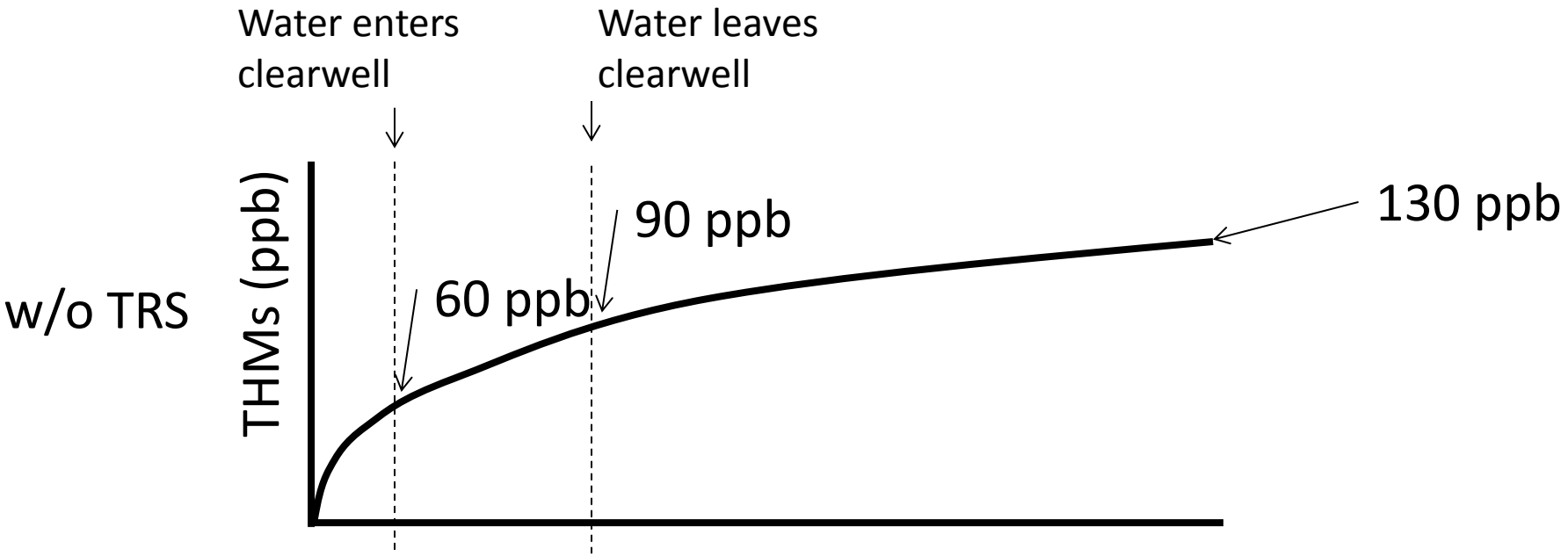
- Significant THM reductions observed just with PAX Mixer and Pax PowerVent
  - Smallest package, fully installed <$30K
- Need a STRONG mixer
  - See our new White Paper on Mixing Power

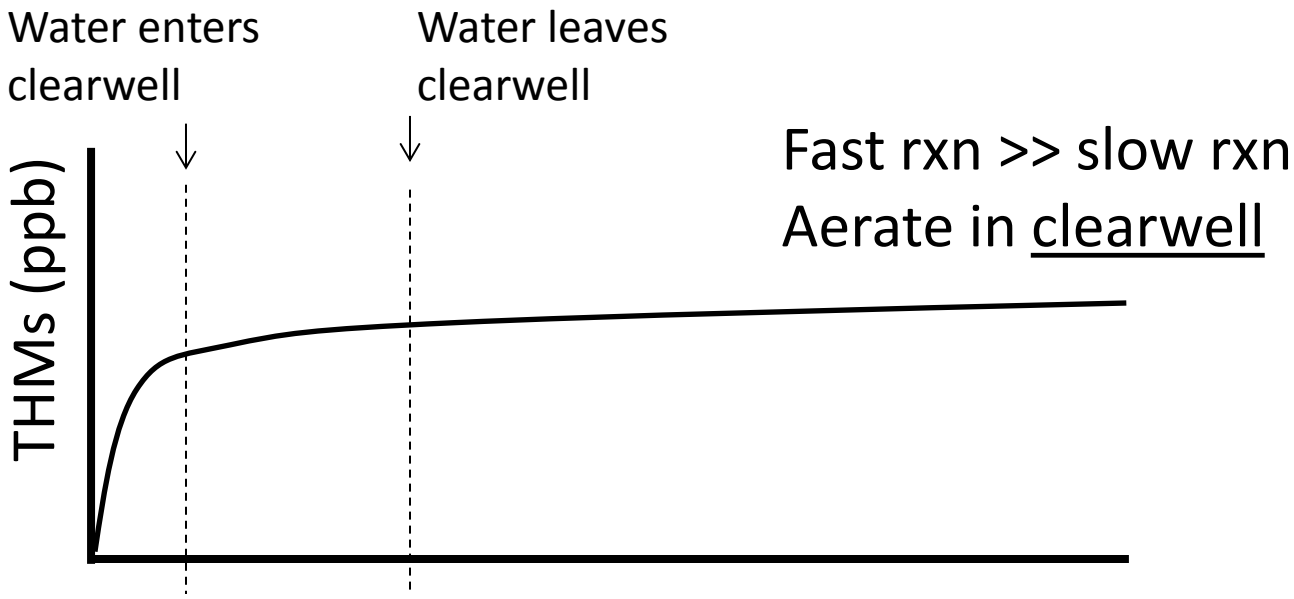
Advantages of this approach:

1. **Quick, economical first step**
2. **Immediate benefits from better mixing**

THMs grow with time… but not steadily







Madison, NC - Clearwell

TRS sprayer manifold mounted in clearwell

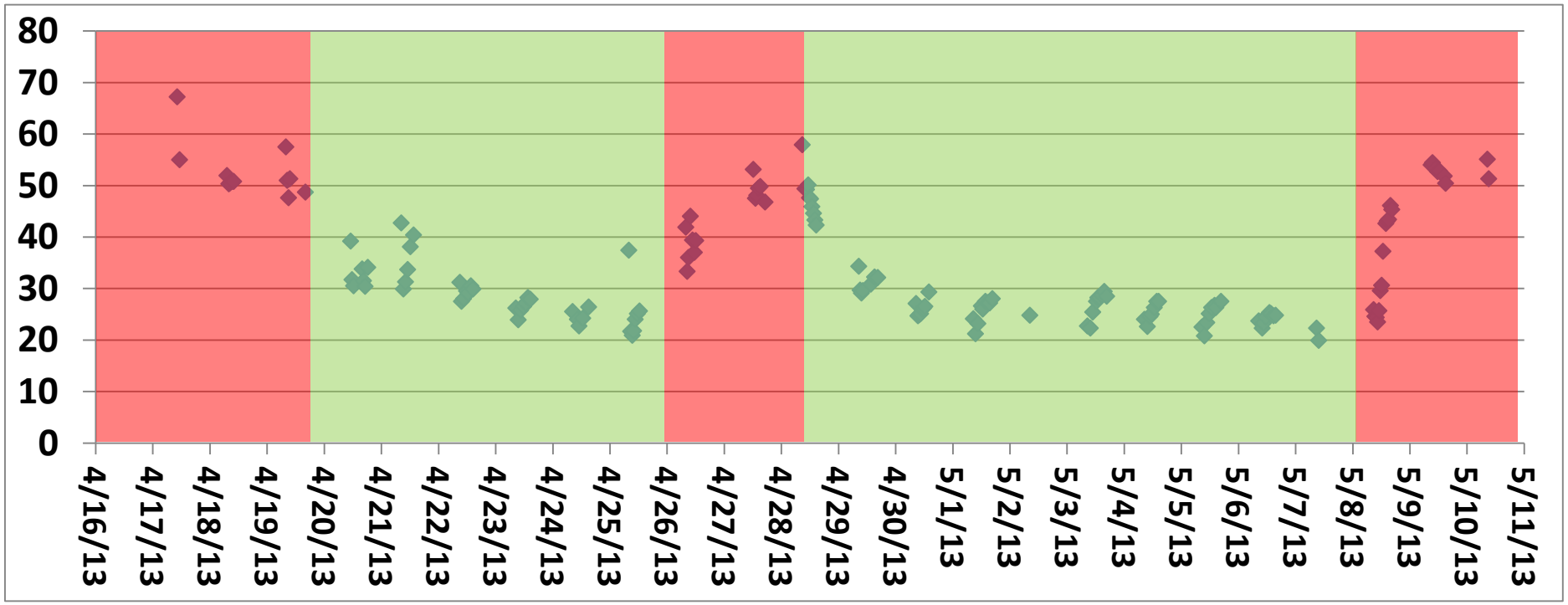
PAX Mixer in Clearwell

Clearwell after TRS installation

Parker Hannifin THM Analyzer

- 30-minute species-specific analysis
- Portable, easy to use
- Requires UHP grade helium

TTHMs (ppb) versus time

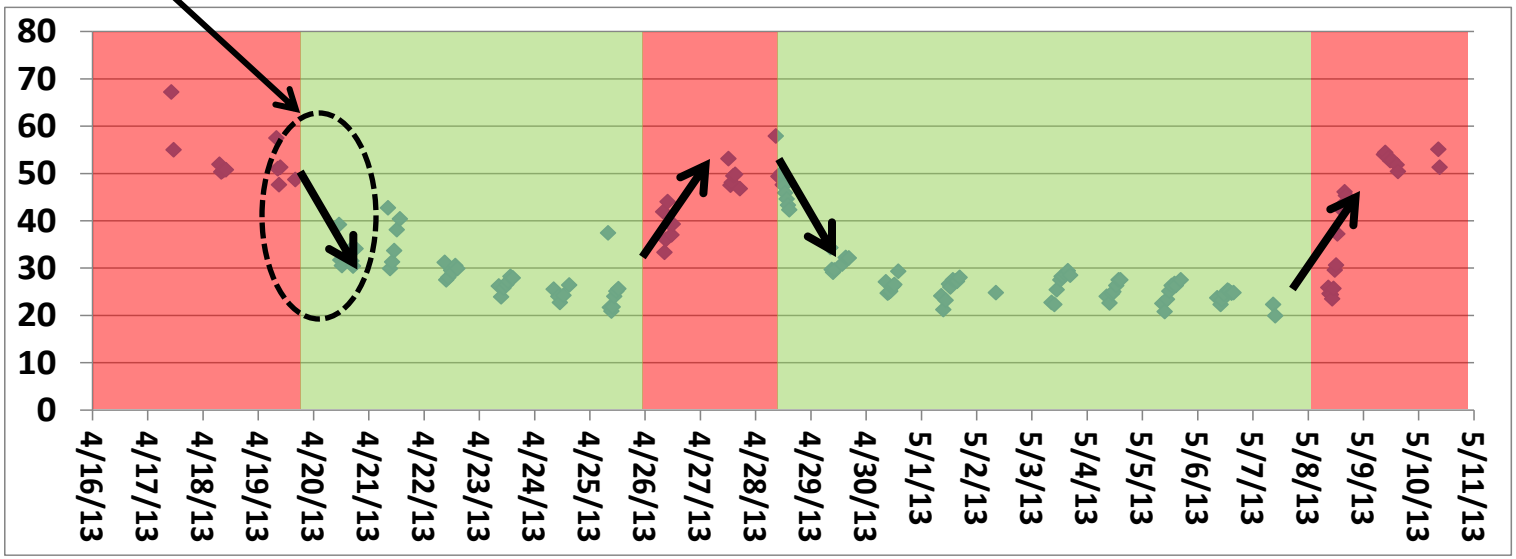


TRS off

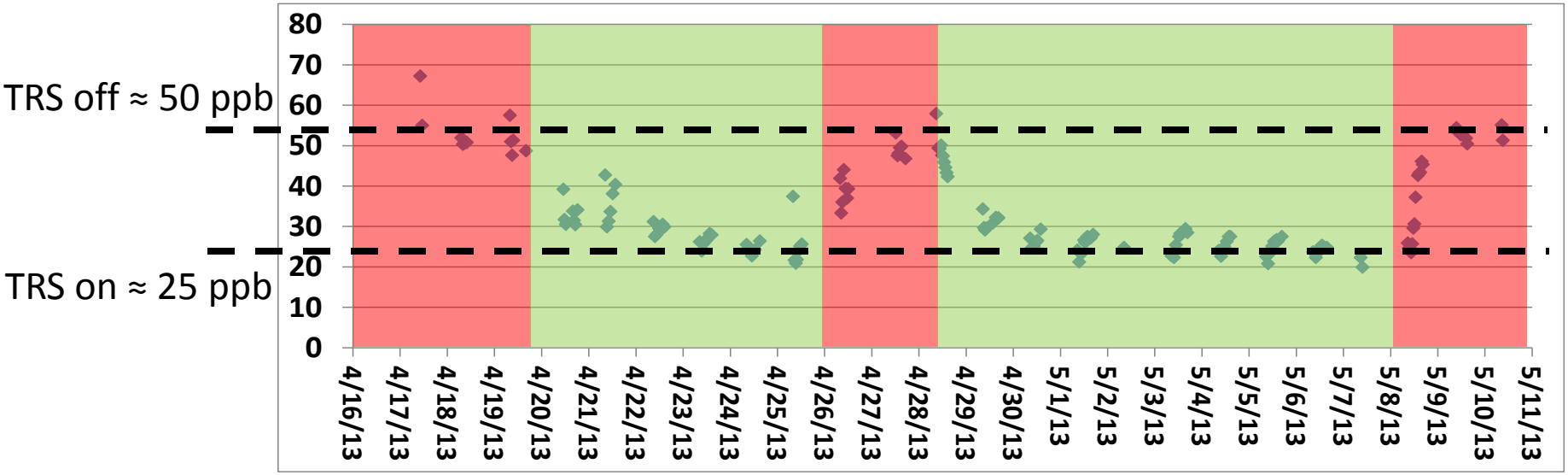
TRS on

Data collected by Madison staff using Parker Hannifin THM Analyzer

Periods of equilibration (~ 1-2 days)



Roughly 50% THM removal



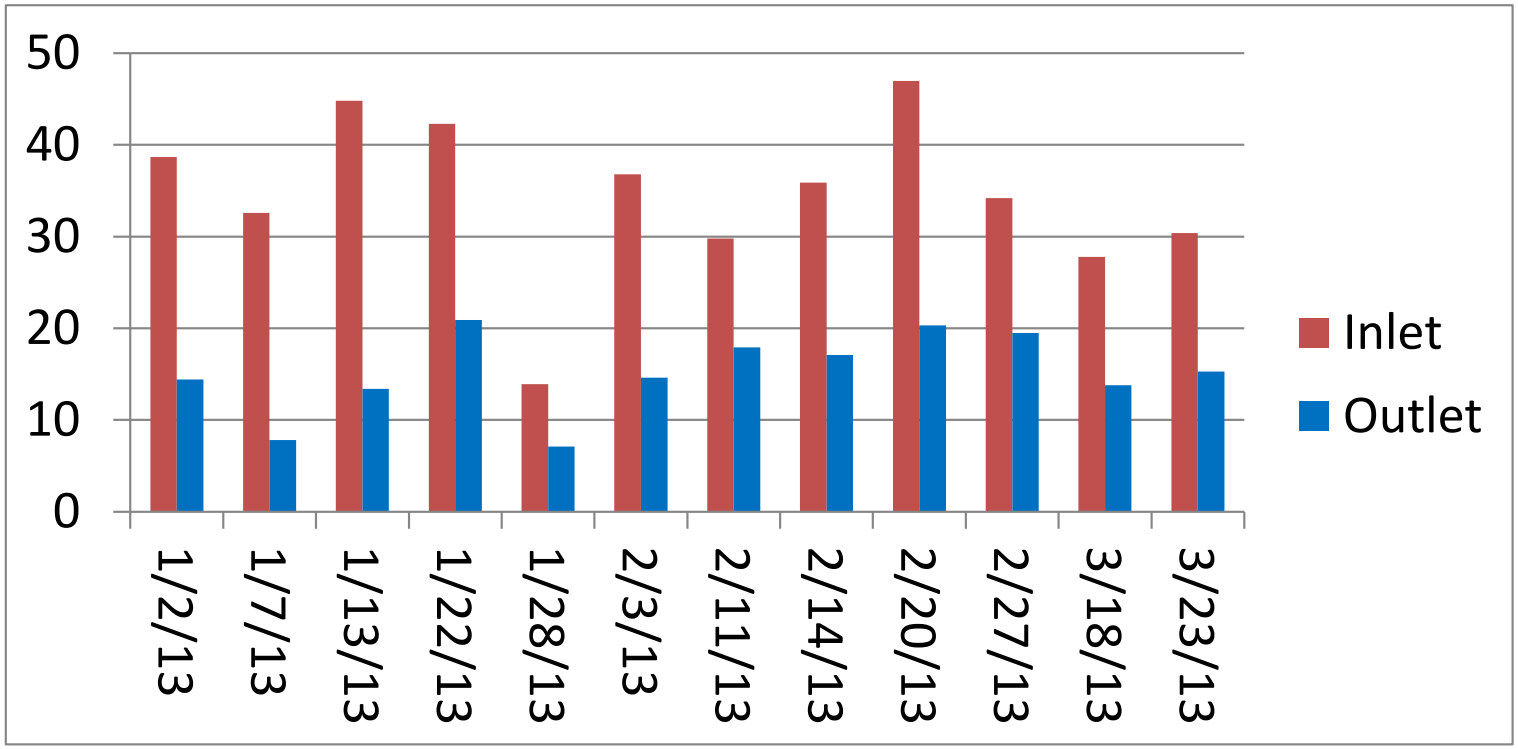
Secondary systems

- No treatment options
- Longer systems, older water
- Engineers: think *systemically*
- Regulators: do NOT let primary systems send barely compliant water to their secondaries!

Madison, NC elevated tank

- Sold water to two small towns
- Water was compliant (barely) as it left Madison system

Madison 704 tank: THM reduction post-TRS



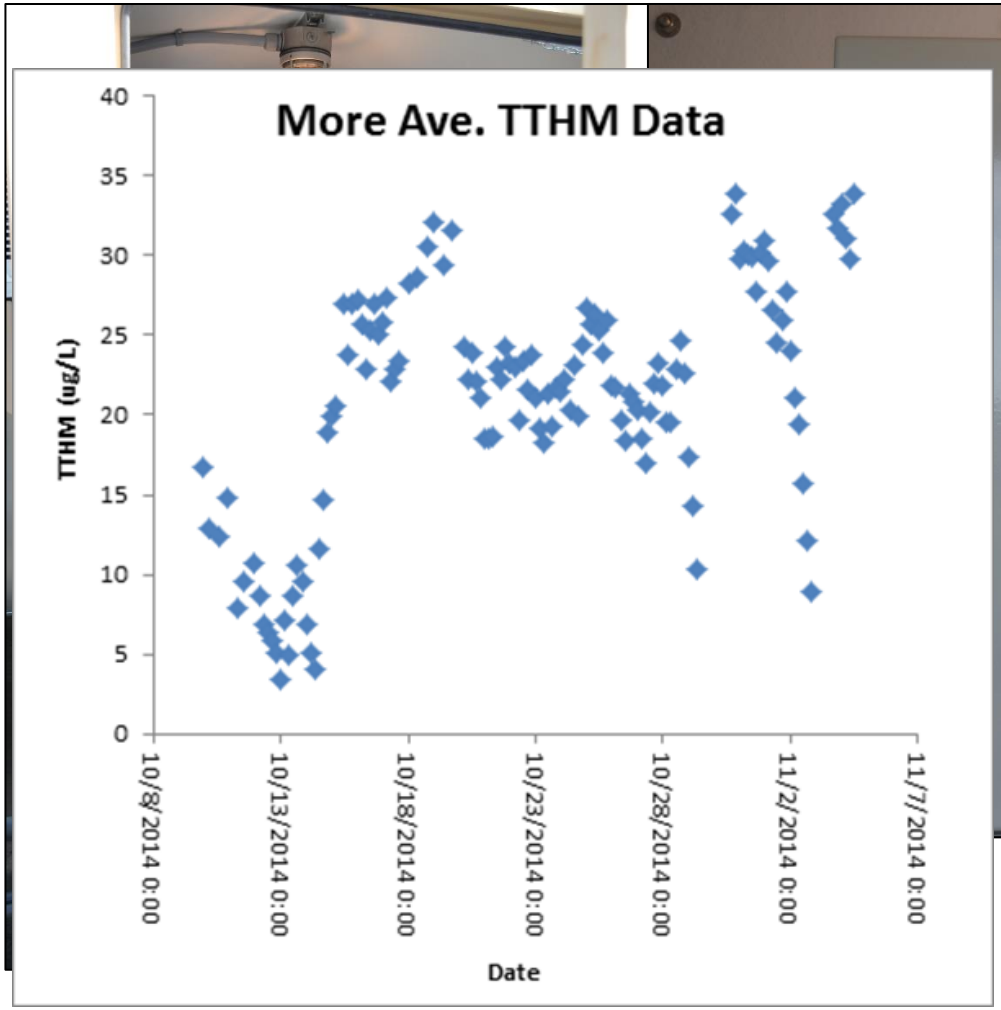
Average = 55% reduction

Secondary systems are now safely in compliance

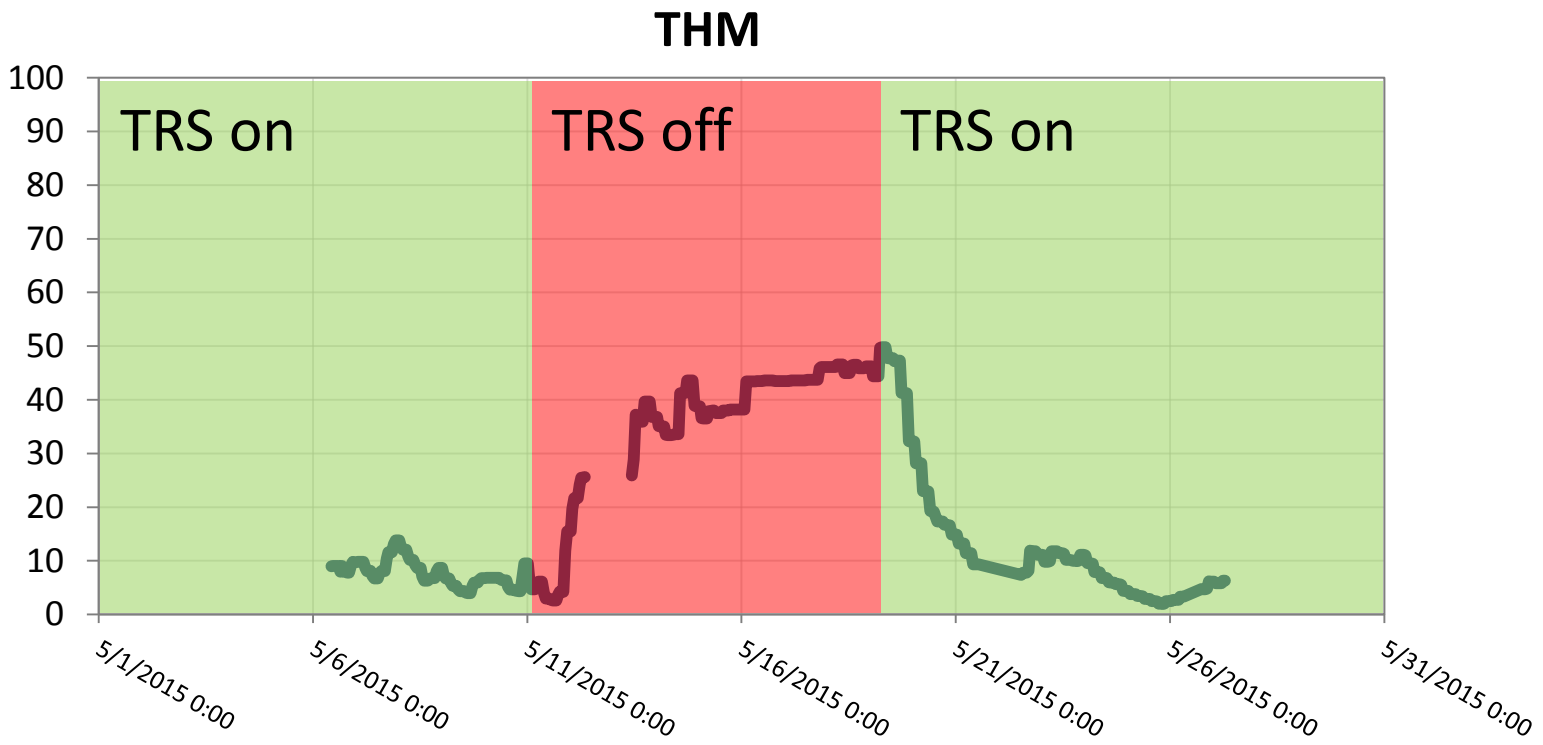
San Jose, CA: 12 MG Reservoir

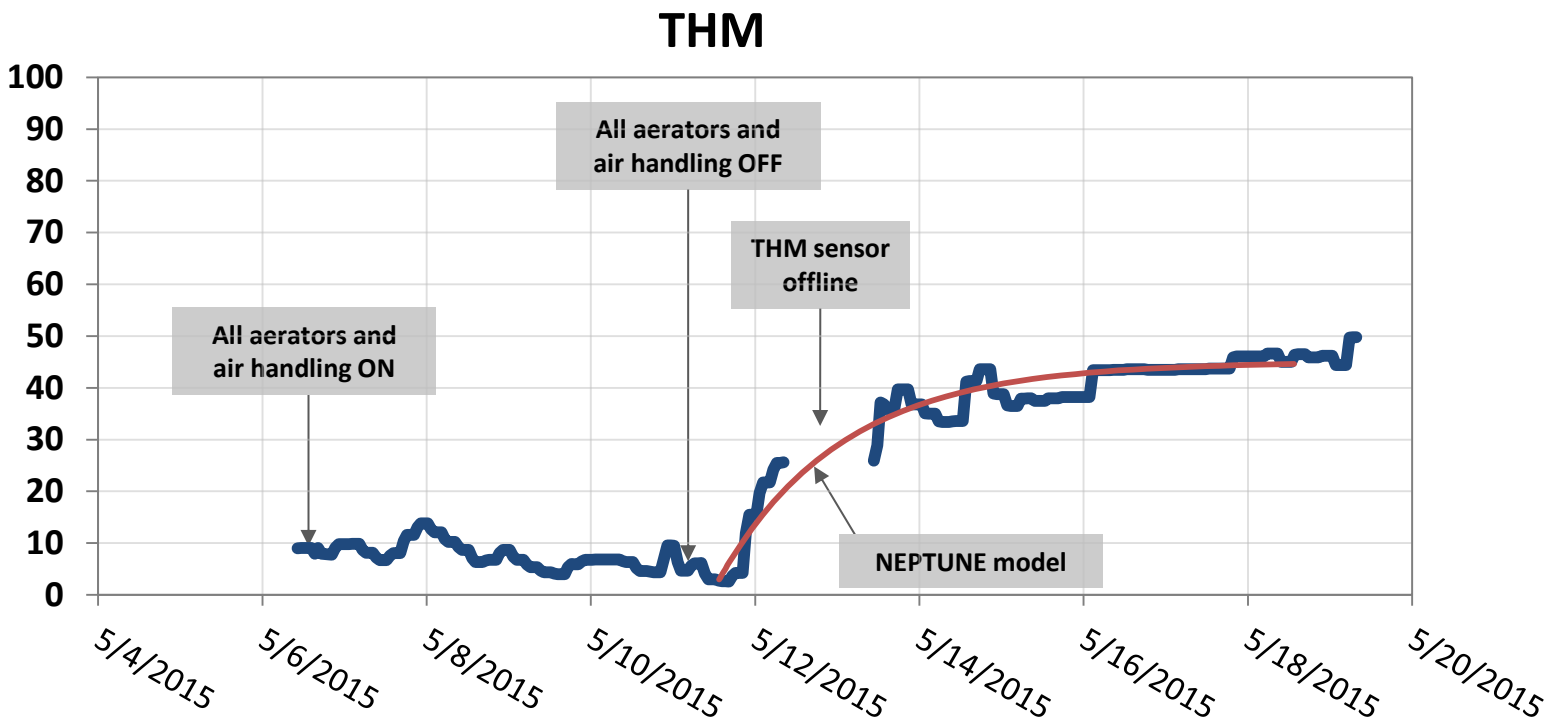
- Purchased water from Santa Clara Valley
- Rising organics and bromide due to drought

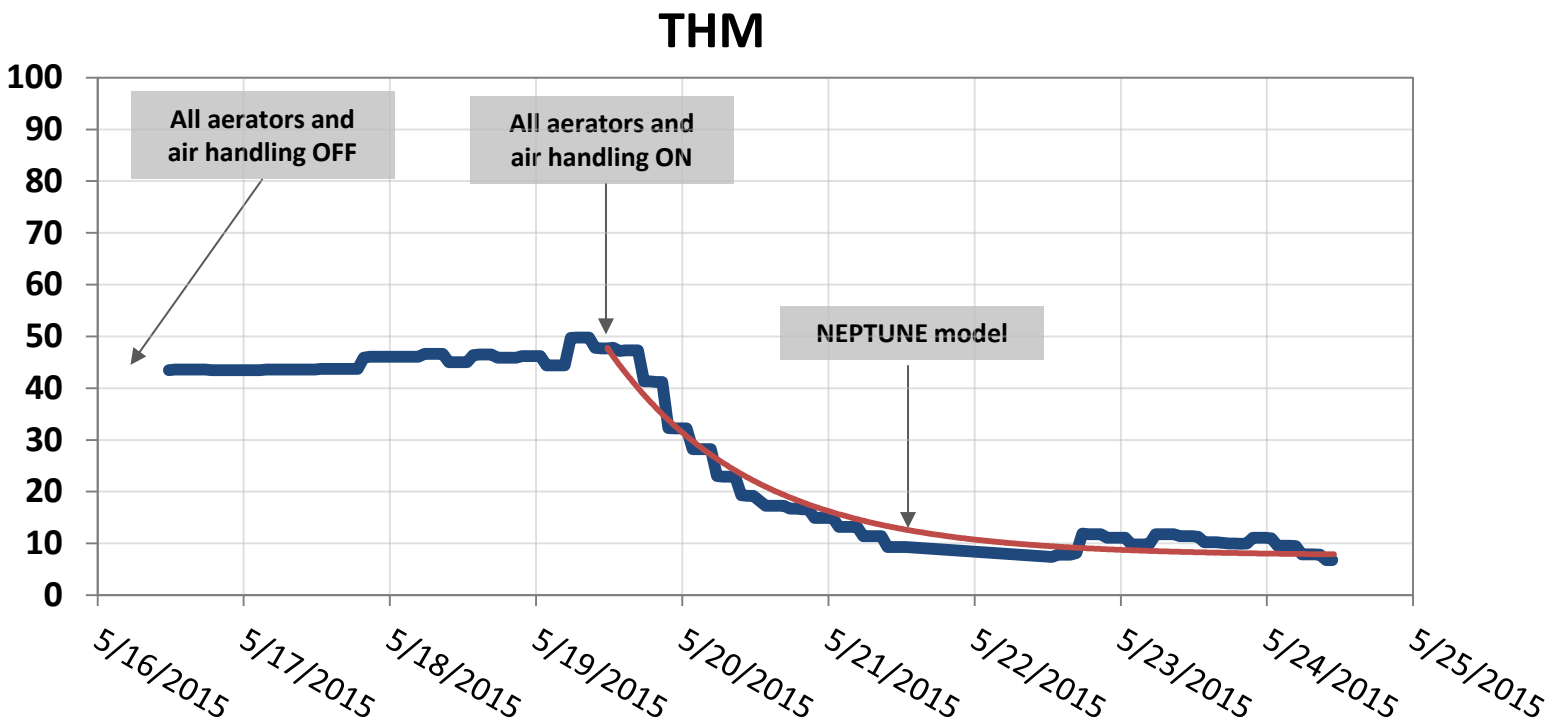
Aqua Metrology AMS-100



60%-75% THM reduction


THM
TRS on
TRS off
TRS on
100
90
80
70
60
50
40
30
20
10
0
5/1/2015 0:00
5/6/2015 0:00
5/11/2015 0:00
5/16/2015 0:00
5/21/2015 0:00
5/26/2015 0:00
5/31/2015 0:00


THM
100
90
80
70
60
50
40
30
20
10
0
All aerators and air handling ON
All aerators and air handling OFF
THM sensor offline
NEPTUNE model
5/4/2015
5/6/2015
5/8/2015
5/10/2015
5/12/2015
5/14/2015
5/16/2015
5/18/2015
5/20/2015


THM
100
90
80
70
60
50
40
30
20
10
0
All aerators and air handling OFF
All aerators and air handling ON
NEPTUNE model
5/16/2015
5/17/2015
5/18/2015
5/19/2015
5/20/2015
5/21/2015
5/22/2015
5/23/2015
5/24/2015
5/25/2015

San Jose, CA – Closed-loop energy optimization

- Control data from THM monitor
- Sequential activation/de-activation of surface aerators
- Potential energy savings of over $50,000/year


San Jose Mercury News

MY TOWN

News Sports Business Entertainment Lifestyle Opinion My Town

Missing San Jose airman found dead by Monterey County dive team

San Jose: Home in east foothills destroyed in 2-alarm fire

Kawak Sandov Giants

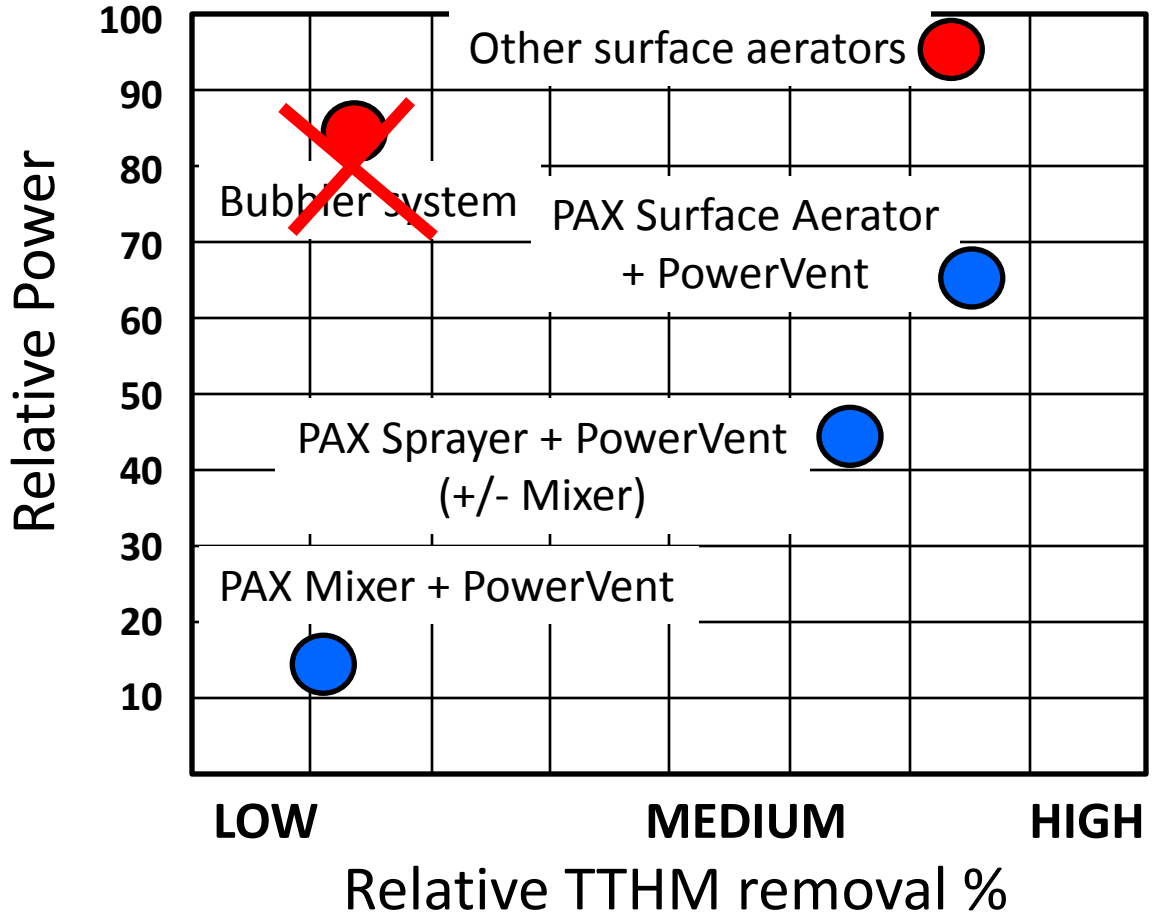
fry's OVER 500 FRESH DEALS WEEKLY

Home My Town Story

Large aerator installed in San Jose water storage to clear out possible carcinogens

By Leeta-Rose Ballester | lballester@community-newspapers.com

Summarizing energy considerations for in—tank aeration systems….



Summary of today's presentation

- In-tank aeration (TRS) is a safe and effective means of lowering THM levels in finished water
  - But NOT a silver bullet!!!
- Different aeration technologies vary in their effectiveness and energy usage
  - Calculate energy consumption per MGD treated
- pH can rise, and Cl can decrease somewhat due to aeration
- The PAX Mixer + active ventilation alone can significantly reduce THM levels