Spray Aeration Improves San Clemente Island Drinking Water

Inexpensive, Simple Technology Reduces Trihalomethane Concentrations

THE USE OF spray aeration technology has proven effective at reducing concentrations of trihalomethanes (THM) in the drinking water system at the U.S. Naval Auxiliary Landing Field, San Clemente Island (SCI), California.

SCI water program managers have been struggling since October 2005 to control high concentrations of THMs in the island's drinking water system, especially during the hot summer months when THM concentrations have been detected above the Safe Drinking Water Act, Maximum Contaminant Level (MCL) of 80 parts per billion (ppb).

For the small water system at SCI, treatment options are limited since everything (including drinking water) has to be barged to the island at high cost. (Costs for everything on the island is triple that of the California mainland.) A simple, but experimental technology, spray aeration, is now keeping THMs under control, below the THM MCL. This technology has an added bonus of improving disinfectant stability in the SCI water system through better water mixing.

San Clemente Island: A Remote Desert Island

SCI is the southernmost island of the Channel Islands off the coast of Southern California. This desert island is approximately 21 miles long and four miles wide (at its widest point) and has no local on-island sources of drinking water, so water must be barged to the island. An offshore bombing range, the island is owned and operated entirely by the US Navy.

The drinking water system at SCI is a consecutive water system—a drinking water system that already receives treated water or "finished" water (potable water) that is ready for human consumption. The SCI barge

San Clemente Island.
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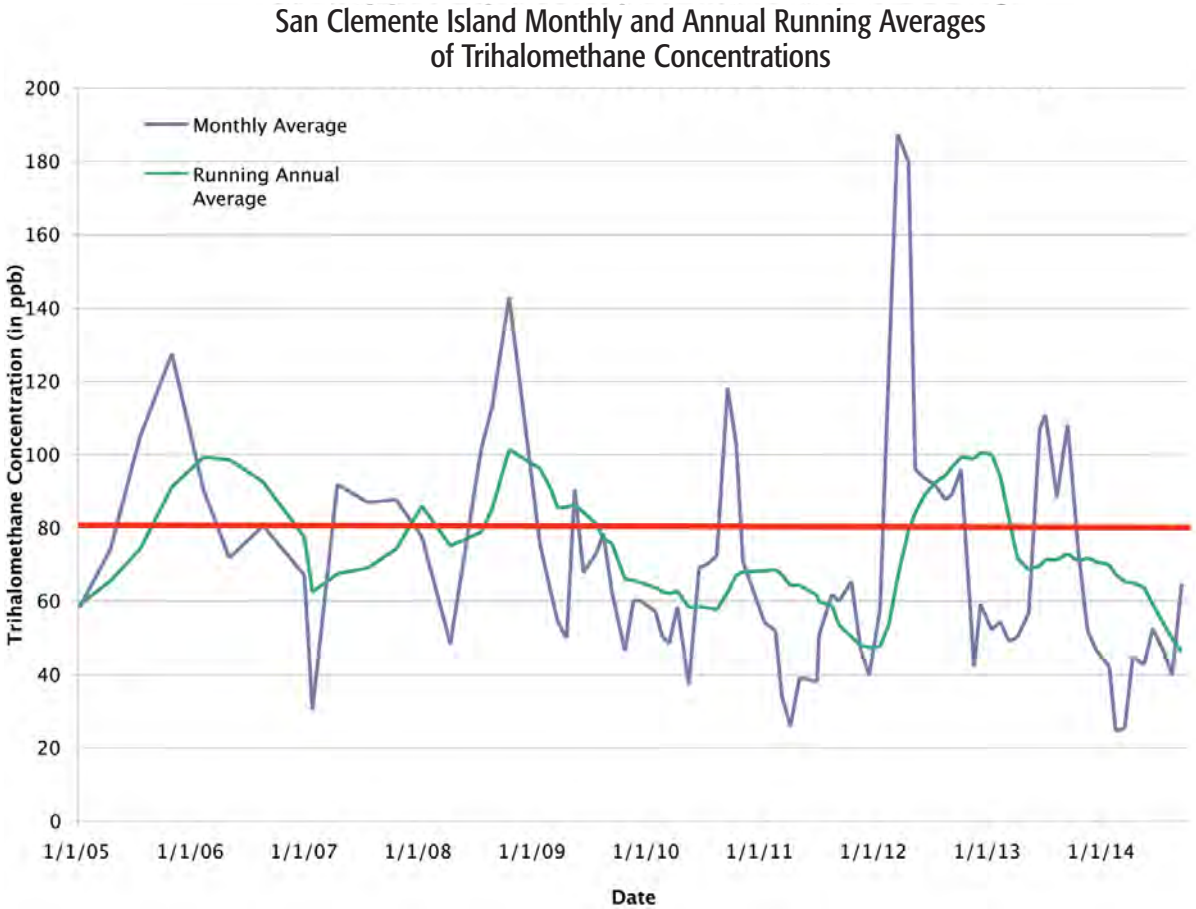
is filled with potable finished water from either the City of San Diego or the Sweetwater Authority (SWA), the same water at all the San Diego area Navy bases. The source water has low concentrations of THMs. Unfortunately, THMs form after the potable water arrives at SCI.

Trihalomethanes Occur in Almost All Drinking Water Systems

To protect people from disease-causing organisms, or pathogens in drinking water, water suppliers often add a disinfectant, such as chlorine, to drinking water. These disinfectants keep the water bacteriologically safe and potable. However, disinfectants can also react with low concentrations of naturally-occurring organic substances in the water to form byproducts such as THMs, which may pose health risks. At SCI, long water age (resident time in storage tanks or reservoirs) create more opportunity for THMs to form and have resulted in THM concentrations over 200 ppb.

U.S. Environmental Protection Agency (EPA) guidance on suitable and economically feasible Best Available Technologies (BAT) for drinking water treatment of THMs in consecutive systems is limited and doesn't include expensive treatment options available to primary water purveyors such as granular activated carbon (GAC). The EPA recognized that consecutive systems are not "primary" water suppliers or purveyors, should be receiving water ready for consumption, and should not be expected to



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significantly treat the supplied water. (Note: "Finished" water is ready for human consumption and may only require disinfectant boosting in some cases.)

Techniques to control THMs in consecutive systems include management of hydraulic flow, including looping water distribution lines to eliminate dead-ends. Looping can be accomplished for some water systems to reduce water age within the distribution system, but may not be accomplished in others with long pipelines. Looping some water lines would cost millions of dollars.

Formation of THMs in SCI Drinking Water

THMS ARE PRESENT in the source water for the SCI barge (SWA and San Diego water) at levels far below the regulatory limit of 80 ppb. When the water reaches SCI, it is placed in the distribution system where it is re-chlorinated, stored, then distributed. The Navy maintains a free chlorine residual throughout the distribution system by recirculation as well as the injection of sodium hypochlorite solution at storage reservoirs on the island. With a long water residence time and a free chlorine residual, THMs continue to form as the chlorine reacts with low concentrations of preexisting precursors (natural organic matter (NOM)) present in the water. THM concentrations also increase with warmer temperatures. All drinking water has some concentration of NOMs. NOMs, measured as total organic carbon (TOC), averaged at a low concentration of two parts per million (ppm) for most of 2008 to 2011.

Because water must be barged to SCI, a reserve of water must be stored for contingencies such as fires or problems with barge deliveries. The water age at various points throughout SCI varies from about three days to approximately two months. Water this "old" must be re-chlorinated multiple times to maintain a minimum safe disinfection level. Most water from a tap should be no older than 3 days from the nearest water tank. THMs are not destroyed by the addition of chlorine, but THMs increase due to chlorination. Multiple chlorination events combined with a long residence time form high concentrations of THM.

Other solutions, such as flushing of water distribution piping is very effective for removing sediment and biofilms in the distribution piping which can contribute to THM formation, but improving the water quality feeding the distribution system from the water tanks is key to maintaining long term compliance with the THM MCLs for consecutive systems.

THM Treatment Alternatives Can Be Complex, Costly & Time Consuming

After receiving the first violation in August 2006 from the California Department of Public Health (CDPH), followed by an EPA Administrative Order (AO) against the Navy in 2007 for exceeding the THM MCL, the Navy wanted to use GAC—the best technology available to reduce THMs at SCI. Unfortunately, the estimated costs to install GAC at SCI were over three million dollars and no space was available at San Diego bases for a GAC treatment system. Producing drinking water from the ocean surrounding SCI using desalination technologies such as reverse osmosis were also cost prohibitive at approximately 21 million dollars. These technologies would also require five to six years (best case) to construct, and would involve complex and expensive environmental permitting for the brine ocean discharge and biological entrainment and entrapment issues with the ocean intake.

In December 2008, the EPA consecutive system BAT was implemented at SCI and the Navy switched from the predominately surface water source from the City of San Diego to the mixed water source (surface, groundwater, and desalinated water) from the SWA. Water storage at SCI was also reduced resulting in an average water age of approximately 20 days from an average of 34 days prior to reduction activities.

In 2009 and throughout 2010 and 2011, the drinking water system at SCI was back in compliance with the THM MCL. It appeared as though the consecutive system BAT was working. Early in this process, the Navy realized that the consecutive BAT may not be the long

term alternative to always maintain the THM concentrations below the MCL at SCI since source water quality can change based on drought conditions and other factors beyond the Navy's control. And future operational needs may increase water age.

In 2012, a THM "perfect storm" hit the SCI water system. The barge was scheduled for regular maintenance and, in anticipation, SCI took on additional water for the time that the barge was expected to be out of service. As a result, the average water age increased. At the same time, SWA provided source water which contained a higher blend of surface water with higher concentrations of NOM. By April 2012, THM concentrations soared and the SCI drinking water system was once again out of compliance with the THM MCL. High concentrations of THMs occurred in the SCI water system until October 2013.

Spray Aeration: Simple & Workable with Existing Tank Recirculation Systems

Spray aeration entails spraying water into the headspace of a water tank to strip volatile THMs from the water. A positive pressure blower with an air filter is used to push fresh air into the tank headspace to remove the stripped THM gases out the tank air vents. At SCI, the existing tank water recirculation systems were modified for spray aeration by adding additional piping and spray nozzles. The design is based on non-clogging (large diameter particle pass-through) spray nozzles (a glorified showerhead) selected for producing the smallest water droplet size (based on water flow rate and pressure) and spray

Spray nozzle.
BETE

Best Available Technology (BAT) for THM/HAA5 Treatment

Primary Water Suppliers

EPA is proposing that the BAT for the THM and Haloacetic Acids (HAA5) Locational Running Annual Average (LRAA) MCLs (0.080 mg/L and 0.060 mg/L, respectively) be one of the three following technologies (for primary systems):

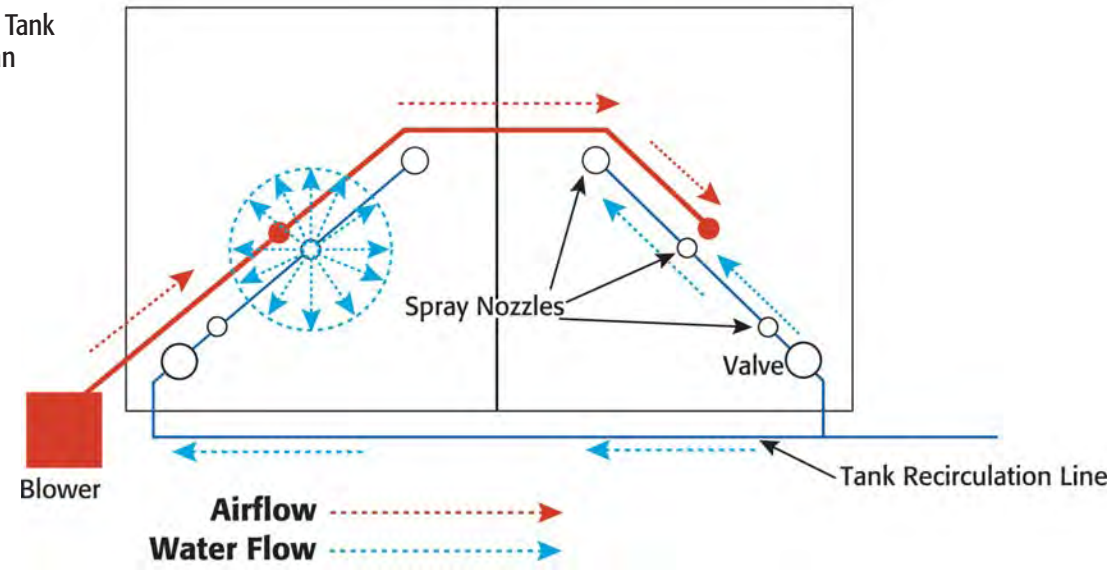
1. GAC adsorbers with at least 10 minutes of empty bed contact time and an annual average reactivation/replacement frequency no greater than 120 days, plus enhanced coagulation or enhanced softening.
2. GAC adsorbers with at least 20 minutes of empty bed contact time and an annual average reactivation/replacement frequency no greater than 240 days.
3. Nanofiltration using a membrane with a molecular weight of 1,000 Daltons or less (or demonstrated to reject at least 80 percent of the influent TOC concentration under typical operating conditions).

Small Consecutive Water Systems

EPA is proposing a different BAT for consecutive systems than for wholesale systems to meet the THM and HAA5 LRAA MCLs. The proposed consecutive system BAT is chloramination with management of hydraulic flow and storage to minimize residence time in the distribution system. This BAT stems from the recognition that treatment to remove already-formed disinfection byproducts (DBP) (like THMs) or minimize further formation is different from treatment to prevent or reduce their formation.

EPA believes that the BATs proposed for wholesale systems are not appropriate for consecutive systems because their efficacy in controlling DBPs is based on precursor removal and each of these BATs, when applied to water with DBPs, raises other concerns. GAC is not cost-effective for removing DBPs. Therefore, GAC and nanofiltration are not appropriate BATs for consecutive systems.

Rectangular Tank Aeration Plan (Plan View)



Rectangular tanks spray aeration configuration.

angle (based on tank configuration) to achieve the longest droplet travel distance. This differs from bubble aeration where air is bubbled into the bottom of the water tank and rising bubbles strip THMs from the water. Bubble aeration needs a large blower to overcome the water pressure in the tank.

Although spray aeration is considered experimental at this point in time, it is slowly gaining acceptance from the regulatory community. The CDPH is overseeing many spray aeration system pilot tests throughout California. A peer-reviewed article only first appeared in the journal of the American Water Works Association (AWWA) in 2011 (Brooke, E, Collins, MR. Post-treatment aeration to reduce THMs. Journal—American Water Works Association). The CDPH and EPA allowed the Navy to conduct its own spray aeration pilot scale test in October 2013.

Initial Spray Aeration Test at SCI

An initial spray aeration pilot test was conducted in October 2013 on a small 10,000-gallon tank at a remote location at SCI (also known as the "P-site") with a long water age and a site subject to high concentrations of THMs. This initial pilot test was installed at minimal cost (less than $5,000 in materials). Water system operators from the Naval Facilities Engineering Command installed a spray nozzle that was rated for 20 gallons per minute (gpm) on the existing water recirculation and booster chlorination system. A blower with piping and electrical rated for an air flow 30 times of the water flow (30:1 air-to-water ratio) was installed to exchange air in the tank headspace. An existing water sampling port on the recirculation line was utilized for water quality monitoring and flows, chlorine concentrations and dosing,

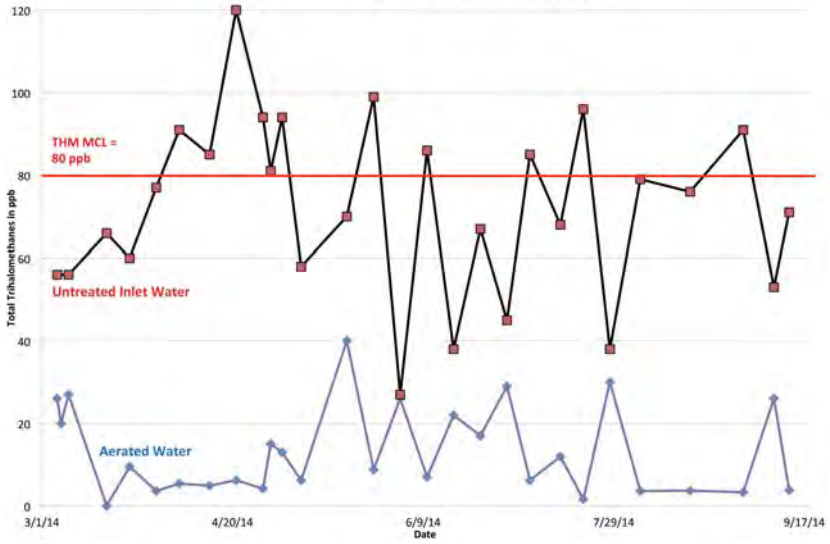
Barge Source Water

THE SOURCE WATER for the SCI barge varies in the level of THM precursors present. These precursors are NOM, sometimes measured as TOC, which reacts with chlorine to form THMs. Barge water had been supplied by the City of San Diego. The City's three treatment plants all treat local and imported surface water with no groundwater sources. The surface water sources have higher NOMs than groundwater or desalination plant sources. The SWA has multiple water sources/treatment plants:

1. The Robert A. Purdue Water Treatment Plant (which treats imported raw and local surface water)
2. The Richard A. Reynolds Groundwater Desalination Facility
3. The National City wells.

The groundwater sources have very low levels of precursors, while the surface water sources are higher. The predominant water blend of water from SWA received at Naval Base San Diego (the location of the SCI barge) is from SWA's groundwater wells and brackish water treated by reverse osmosis.

P-Site Tank Aeration Pilot Scale Test Results:
Total Trihalomethanes (ppb)



P-Site Tank: Percent THM Removed

and THM concentrations were assessed as part of this initial test. Initial pilot test results were very promising. Over ten days, approximately 90 percent of the THM were removed from the tank water. Chlorine usage by the chlorine injection system did not increase, indicating that the chlorine in the water was not being stripped by the spray aeration system. In fact, it appeared that chlorine concentrations in the tank were more stable, indicating better mixing and less chlorine demand in the tank water.

Expansion of Spray Aeration System at SCI

This initial success was reported to the CDPH and EPA in January 2014. Immediately after, the Navy proposed upgrading the P-site aeration system and expanding the spray aeration system to all tank systems at SCI. The CDPH and EPA immediately accepted the proposed system upgrades and expansion. The upgrades and additional tank aeration systems were installed and operational throughout the first and second quarters of 2014. Total material and installation costs for the spray aeration system for the entire SCI water system were below $75,000.

Aeration piping on a 40,000-gallon tank. Outside pipe is water heading up for spraying and inside pipe is the injected air pipe.
Thomas Niday

Spray Aeration Results: SCI Back in Compliance

Untreated inlet water to the P-site tank was over 80 micrograms per liter (µg/l) throughout the early part of 2014. Fortunately, during this time, spray aeration removed an average of 76 percent of the THMs. This resulted

San Clemente Island is now back in compliance with the trihalomethanes Maximum Contaminant Level.

in THM concentrations being maintained below 80 µg/l in the downstream compliance monitoring location. It is estimated that spray aeration removed from 56 percent to 86 percent of the THMs in the Rectangular Tank water (from the dual set of SCI water tanks), averaging 67 percent removal efficiency overall. SCI is now back in compliance with the THM MCL.

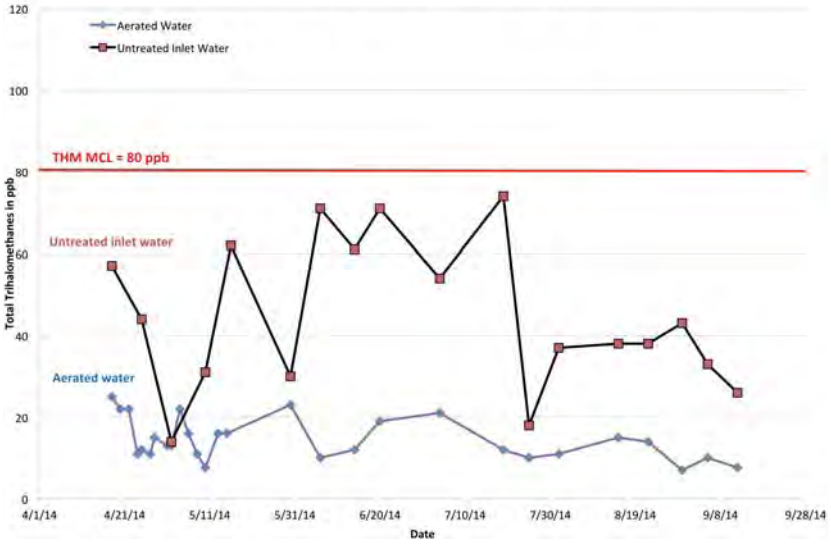
One of the main concerns expressed about spray aeration was that the chlorine disinfectant was going to be stripped from the water. To keep the water safe, chlorine must be maintained in the water. In reviewing chlorine dosing data from before and during aeration, it appears that chlorine is not stripped, and in fact, chlorine dosing rates are lower. Chlorine dosing rates are half that of non-aeration rates. It appears that spray aeration enhances the mixing of chlorine in the water tanks. Since chlorine in water doesn't exist as a gas but as aqueous hypochlorous acid (HClO), the chlorine will not be air-stripped from the water.

Overall THMs were reduced in the water reservoirs and at the compliance monitoring points at SCI due to a combination of:

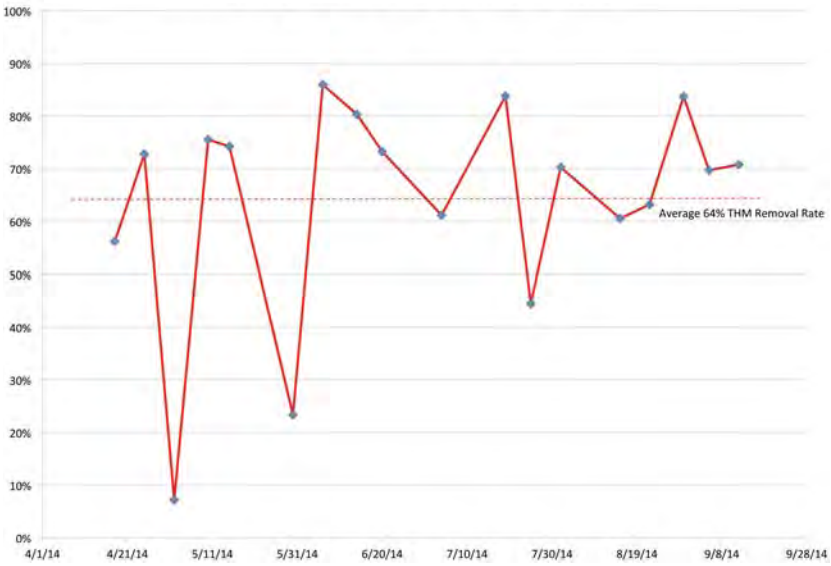
1. Source water with low TOC concentrations from SWA.
2. Relatively low water age (currently 26.9 days).
3. Better water mixing in tanks (from both mixers and aeration).
4. Stripping of THMs using spray aeration.

Based upon these results, both the EPA and CDPH are inclined to close the EPA AO in the fall of 2014.

Rectangular Tanks Aeration Pilot Scale Test Results: Total Trihalomethanes (ppb)



Rectangular Tanks: Percent THM Removed

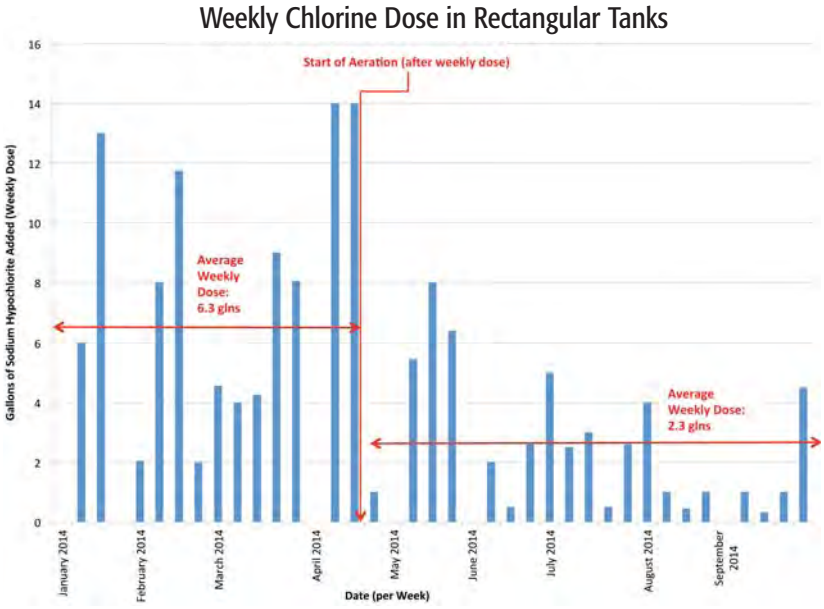


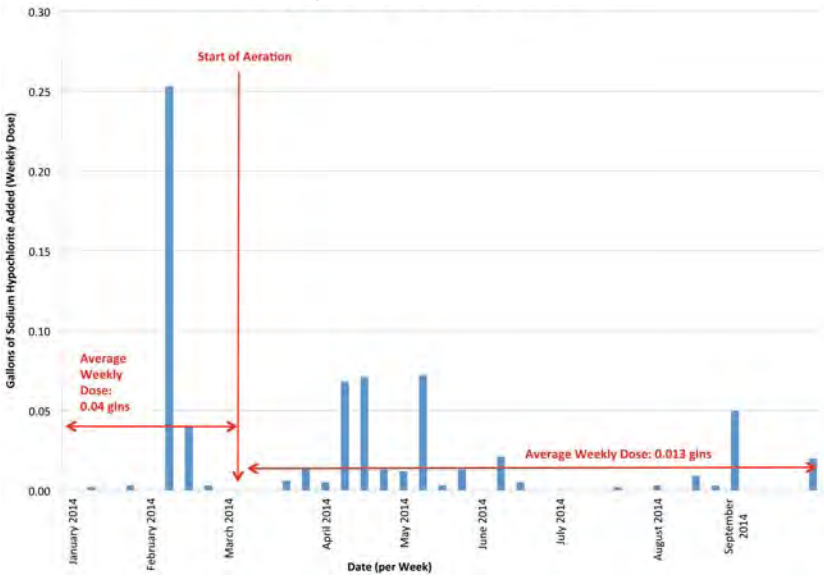
Recommendations for Navy Water Systems

EPA BATs for consecutive systems may work in some water systems with short average water ages, but as the SCI example shows, for water systems with long water ages, these BATS may only work in the short

Water spray in a 40,000-gallon tank. Water is dropping eight feet.
Thomas Niday

term. Hydraulic control measures such as looping water distribution lines can reduce water age and associated THMs within the distribution system, but may not be feasible in water systems with long pipelines due to high costs.





Unidirectional flushing of water distribution piping is very effective for reducing chlorine demand and THM formation within the distribution system, but improving the water quality feeding the distribution system from the water tanks is key to maintaining long term compliance with the THM MCL. A combination of internal tank mixers combined with spray aeration worked where the source water quality can change and water age is long. In some cases, a small tank with a spray aeration system and a chlorine booster may reduce THMs significantly for dead-end and/or remote areas at the end of long pipelines of a distribution system. Spray aeration also stabilizes chlorine levels in the tanks and distribution system, reducing the amount of chlorine dosed in the system.

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