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The Skyco Water Treatment Plant – Anion Vessel Evaluation

Prepared for

County of Dare Water Department

Black & Veatch Project No. 161371

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SECTION 1. INTRODUCTION

The Skyco WTP was constructed in 1979 as primarily a softening facility, but was retrofitted in 2003 with an anion exchange unit for total organic carbon (TOC) removal. The facility has a capacity of 4.3 mgd. The plant runs at capacity approximately 5 months a year to help meet summer demands, but reduces to 1 to 2 mgd during off-season months. Inadequate TOC removal through the facility is presently resulting in elevated disinfection by-products (DBPs), most notably total total trihalomethanes (TTHMs), which is generating potential compliance-related issues.

Based on a variety of factors, it appears that the anion exchange resin is reaching the end of its expected life. Changes have been observed in physical character of the resin, and the reduction in process effectiveness indicate that the resin should likely be replaced this year. In addition, the long-term viability of the technology should be reviewed pending capability to resolve operational challenges with the recommended modifications and capability to meet forthcoming regulations.

To this end, Black & Veatch conducted an engineering study to primarily identify strategies to optimize the current operation to maximize the anion exchange system for TOC removal and disinfection by-product precursor removal. This report summarizes these findings.

SECTION 2. FACILITY LAYOUT AND OPERATION

As noted previously, the Skyco WTP is a 4.3 mgd softening and TOC removal facility. The facility utilizes nine wells ranging from 180 to 220 feet deep, tapping a fresh water aquifer. The raw water TOC is typically around 3 mg/L and the facility was intended to target 60 to 80 percent removal of this TOC through the treatment process before entering the clearwell. However, even with relatively low TOC entering the clearwell, the chlorine demand across the clearwell has typically been approximately 2 mg/L, requiring an additional 1.5 to 2.0 mg/L of chlorine for a distribution system residual. Ultimately, this results in THM levels in Manteo ranging from 39 to 92 ug/L range (maximum allowable annual averages are 80 ug/L).

Table 1 below summarizes some of the known key raw water quality parameters.

Table 1 - Key Skyco WTP Water Quality Parameters

Raw Water Quality[1]	
TOC, mg/L	2.9 ± 0.5
Color, unit	18 ± 4
pH	7.7 ± 0.1
TDS, mg/L	299 ± 24
Sulfate, mg/L	Not detected
Chloride, mg/L	55 - 100
Total Hardness, mg/L as CaCO3	183 ± 12

(1) Raw water data except chloride obtained from "Color and THMFP Removal Pilot Test at Dare County Water Treatment Facilities", dated June 1998, prepared by Boyle Engineering Corporation. Chloride data obtained from plant staff.

In addition to this data, according to the December 2007 Monthly Monitoring Report, the raw water iron levels ranged from 0.16 to 0.44 mg/L, with staff reporting that raw water levels have reached as high as 0.57 mg/L. Typical levels in the softener effluent are approximately 0.02 mg/L.

The physical configuration of the facility is very tight. Water from the wells is combined in a common header and is distributed to four ion exchange softening units. Each unit treats a maximum of 800 gpm and utilizes approximately 146 cubic feed of softener resin (US Filter C-211). The softener resin was replaced last year and historically has lasted approximately 10 years. The softeners have been regenerated every 350,000 gallons of throughput in the past, but more recently this throughput has been increased to improve operating efficiency and reduce the extent to which these units must be bypassed. This process takes approximately 1.5 hours. Plant staff indicates that the water flow split between the different softeners seems to be relatively well balanced.

Following the softeners are five anion exchange reactors which were installed in 2001. Table 2 below summarizes some of the key anion vessel design criteria.

Table 2 - Key Anion Vessel Design Criteria

Design Parameters for Anion Exchange System – Dare County Skyco WTP[1]	
Vessel Diameter, ft	12
Number of Vessels	5
Resin Depth, ft	6
Resin Volume per Vessel, ft^3	679
Vessel Flow (nominal), gpm	625[2]
EBCT, min	8.1
Surface Loading, gpm/ft^2	5.5
Backwash Flow, gpm	340
Regenerant Flow (10% solution brine), gpm	52
Slow Rinse Flow, gpm	52
Fast Rinse Flow, gpm	625
Regeneration Period, hours:	5.5
Backwash, min	10
10% Brine, hours	2.5
Slow Rinse, hours	2.5
Fast Rinse, min	20
Regeneration Mode	Down-flow

(1) Data obtained from "Design Manual for Anix Color Removal System – Skyco Water Treatment Plant – Dare County, North Carolina", dated September 20, 2000 (Revised December 1, 2000), prepared by Quible & Associates, P.C., Boyle Engineering Corporation, and RosTek Associates, Inc.

(2) Maximum vessel flow is 694 gpm.

According to the available data and information provided by the plant staff, the anion exchange system did reduce TTHMs during the first few years of operation; however, the TTHMs increased in 2005. They have declined somewhat since that time, but are still higher then pre-2004 levels. Figure 2-1 and Figure 2-2 summarize some of the historical TTHM and HAA5 information available, respectively, between 2003 and 2007. It should be noted that HAA5 levels are extremely low relative to the regulatory limits and do not appear to be an issue for the Skyco WTP. Figure 2-3 and Figure 2-4 summarize the locational running annual averages (LRAA's) for the TTHM and HAA5 levels from the Skyco WTP, which are the actual regulatory basis for compliance (80 ug/L for TTHMs and 60 ug/L for HAA5s).

Figure 2-1 - TTHM Values – Skyco WTP Sites

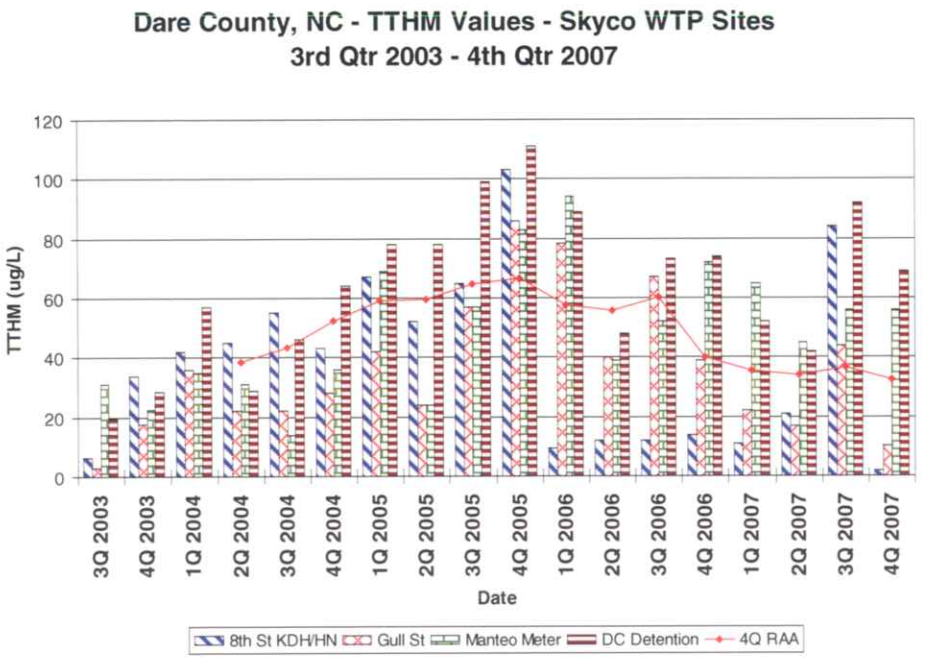


Figure 2-2 - HAA5 Values – Skyco WTP Sites

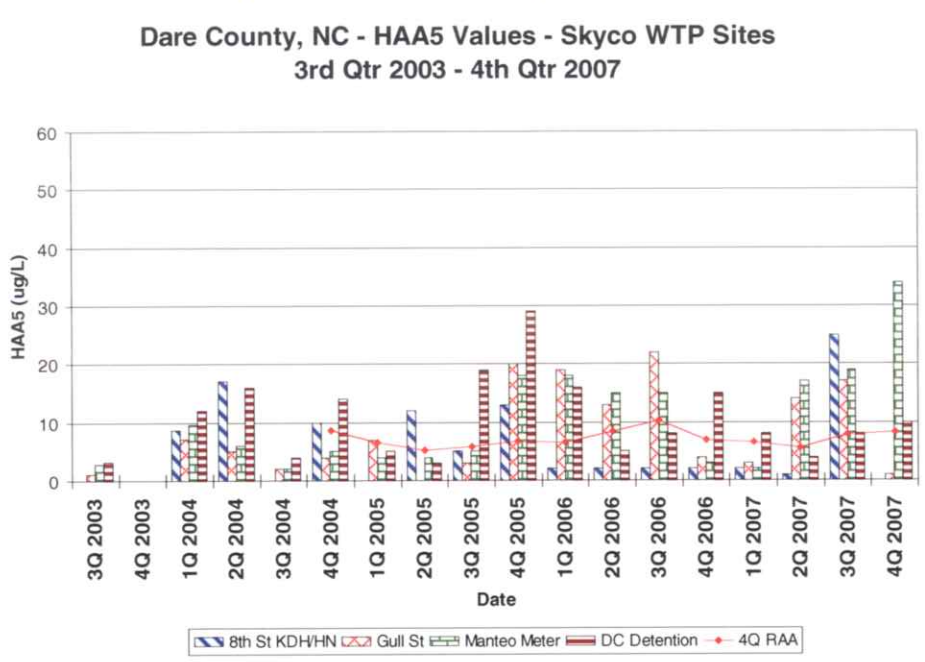


Figure 2-3 - TTHM LRAA Values – Skyco WTP Sites

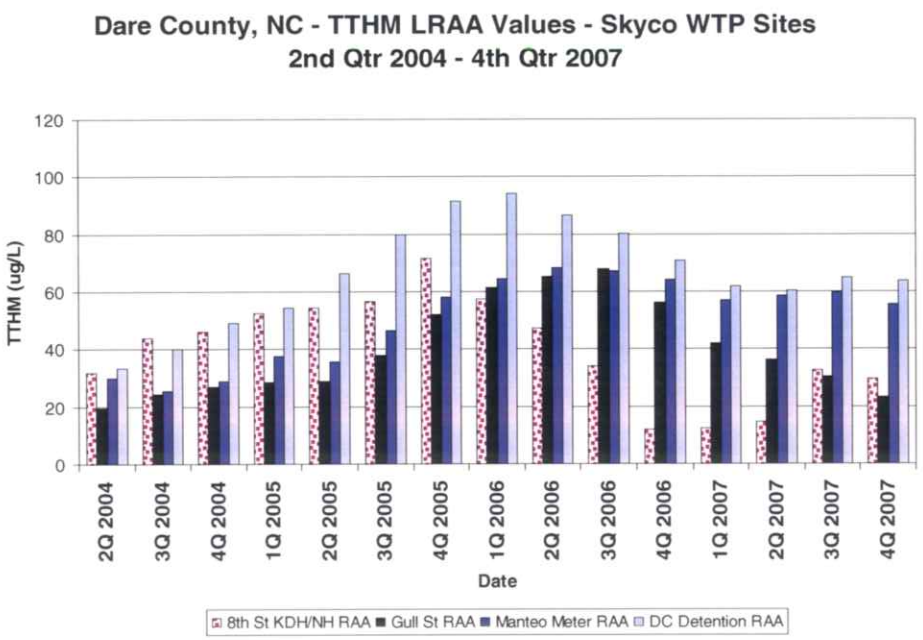
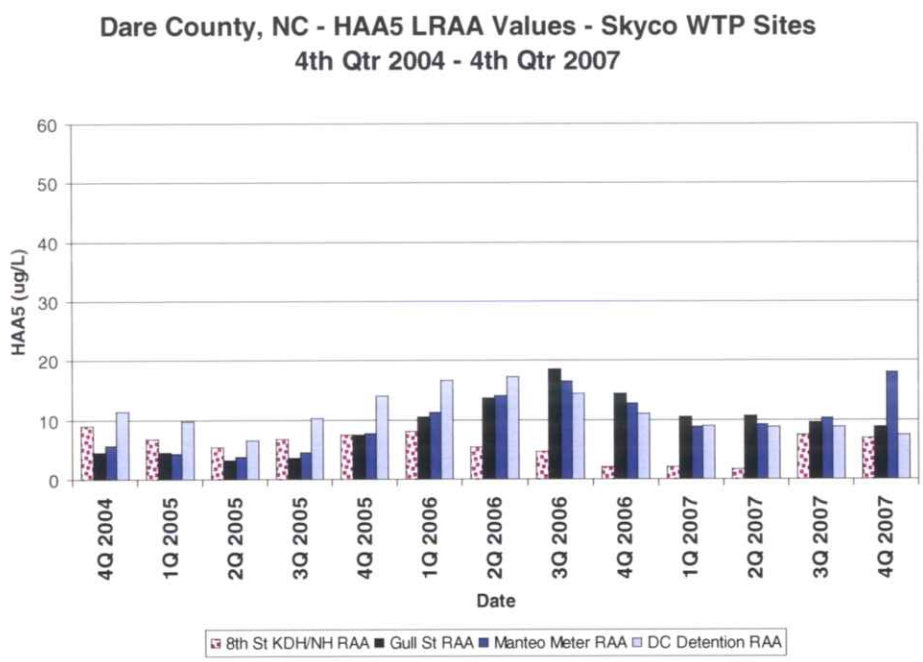


Figure 2-4 - HAA5 LRAA Values – Skyco WTP Sites



A significant issue with the anion exchange system is that the backwash/regeneration/rinse process is taking significantly longer than originally anticipated. It currently takes over 10 hours to effectively backwash a vessel, which is nearly twice the 5.5 hours originally intended as shown in Table 2. According to Plant staff, it only recently took approximately 190 gpm to effectively backwash (original maximum backwash flow was 140 gpm), whereas the required backwash rate has increased to nearly 300 gpm to fluidize the vessel resin. While this is still

within the original design of 325 gpm as initially specified as shown in Table 2, this is still more than what had historically been required by the facility. It should be noted that the resin specification sheet indicates a backwash flow rate of 0.1 to 0.5 gpm/cf of resin. This corresponds to a backwash rate of 68 to 340 gpm. Therefore, the current backwash rate may suggest that the resin has fouled significantly.

Some of the increased backwashing requirements may have resulted from observed failures of anion vessel valves that are associated with the backwash process. This would have resulted in poor backwash conditions at some period during the life of the resin, resulting in a fouling condition that could have created channeling through the resin. This is a condition that would reduce backwash and rinse efficiency, as well as process performance of the resin for TOC removal.

The anion resin utilized at the Skyco WTP is a ResinTech SIR-22P-HP resin specifically designed to remove naturally occurring organic matter. According to the resin's specifications, it has an approximately 70 to 85% water retention rate. In some cases, this high level of water retention may reduce the ability for resin to release bound organics during a regeneration cycle. This is a characteristic of styrenic type resins (high water retention rates), such as the ResinTech SIR-22P-HP utilized at the Skyco WTP.

This is contrasted with the more successful application of an acrylic type resin at the Frisco plant that has exhibited much better success for removal of TOC. In addition, the total downtime for backwash, brine application, and rinsing is 3.5 hours at the Frisco plant as compared to a time of 10 hours at the Skyco plant.

In general, the existing anion exchange resin is presently only removing approximately 45% of the source water TOC. In many cases, removal is less than 20% according to the available data. Table 3 below summarizes the TOC removal data available from 2006 and 2007. Greater TOC removal was expected through the anion exchange vessels offering further indication that the resin is reaching the end of its serviceable life.

Table 3 - 2006 and 2007 Skyco WTP TOC Removal Summary

Date	Raw TOC (mg/L)	Finished TOC (mg/L)	% Removal	Distributed TOC (mg/L)
Average	2.47	1.46	45	1.55
Minimum	0.01	0.01	0.0	0.03
Maximum	7.8	7.9	99.6	4.69
95th percentile	4.84	2.9	91.0	2.75

Water flows from the anion exchange vessels to the onsite 2 MG clearwell prior to distribution. Approximately 2 mg/L of chlorine has historically been feed to the clearwell feed, often with <0.5 residual remaining immediately prior to high service

pumping, which requires additional post-chlorine feed to provide a chlorine residual of 2.0 mg/L leaving the facility. The transmission pumps can provide up to 5,000 gpm to the beach area, and the high service pumps can provide up to 1,000 gpm to the Town of Manteo.

In addition, chlorinated clearwell water is used as the source for anion vessel backwashing. This water is not de-chlorinated prior to use as a backwash water supply. While chlorine can damage an ion exchange resin, reported levels of chlorine in this water supply are generally less than 0.2 mg/L, which may be within acceptable levels relative to chlorine tolerance of the resin. In spite of this, provision of a dechlorination capability would provide better flexibility for assuring low chlorine content backwash water.

SECTION 3. PHYSICAL ISSUES WITHIN THE TREATMENT FACILITY

There are a number of physical issues within the facility that impact overall performance. Some of these areas can potentially be improved, but others, without wholesale changes and modifications to the facility, will be difficult to implement.

- The Plant currently produces 3.8 to 4.2 mgd. There are major restrictions in head loss due to anion resin fouling. However, there does not appear to be any redundancy within the plant. Typically, most WTPs are rated such that they can produce the designed finished water volume with the largest process train out of service. The softener units are sized at approximately 800 gpm, so with one out of service, that results in a reliable capacity of approximately 2400 gpm, or approximately 3.5 mgd. The anion vessels are rated at 625 gpm each. With one vessel out of service, the firm capacity of the anion process flow is approximately 2500 gpm, or 3.6 mgd.

  The full capacity of the plant is presently being sustained during a regeneration by bypassing a portion of the flow around the softening resins. The lack of treatment of this portion of the flow may have an effect on the existing anion exchange resin. However, it is noteworthy that the acrylic-based anion exchange resins at the Frisco plant do not exhibit degradation in spite of the absence of softening and much higher raw water TOCs (< 13 mg/L). This may be due to different resin attributes.

  Analysis of samples of the existing anion exchange resin should provide some information on the factors that are affecting resin changes and may allow some decisions regarding the importance of softening as a pretreatment step prior to the anion exchange vessels.

- The feed pressure increases significantly when a softener goes into a backwash mode. Typically, the operating well pumps that are in service at the time of backwash initiation will continue to operate throughout the softener backwash sequence, unless they are turned off manually by Plant staff. As such, when the feed pressure to the softeners gets very high, up to 75 psi, some of the wells need to be shut off to reduce pressure and allow the softerners to regenerate. The availability of VFDs for flow control will provide greater flexibility for operation of the system in the future.
- Due to the design of the anion vessels, there is very limited access to the vessels. Physical access is very problematic, so routine maintenance and verification of resin performance is very difficult. Furthermore, visual inspection is difficult as well.
- There is limited flow control through the WTP and limited ability to control or monitor any bypass flows.

- While it was difficult to assess during the plant visits, it appears there is limited control of well pumps from the WTP. This limits the ability for the plant operators to effectively cycle through wells based on raw water quality and sequence of operating at the WTP (i.e. softener being in backwash mode). Availability of VFDs on the well pumps would improve flexibility for controlling the operation of the well pumps.
- According to staff, up until recent months, there was a large chlorine demand occurring in the clearwell, even though there was a relatively low amount of TOC (typically approximately 1.5 mg/L) present. A chlorine demand of 2 mg/L was common, which is a very large demand relative to the amount of TOC entering the clearwell.

As shown in Figure 3-1 and Figure 3-2, a large amount of organic debris was removed from the clearwell drain line when the clearwell was drained and cleaned during the course of the study. This could have been a factor that affected the level of DBP's leaving the facility, especially considering the high chlorine demand historically realized across the clearwell in relation to a relatively low TOC that entered the clearwell. Initial DBP sampling after the clearwell was drained and the debris removed was promising as the TTHMs leaving the WTP were less than 5 ug/L based on the laboratory analysis; However, subsequent compliance sampling results are still pending as those initial results appear somewhat questionable. In any case, the removal of that debris from the clearwell should reduce the chlorine demand historically realized through the clearwell, subsequently reducing the THM formation to some degree in the distribution system.

Figure 3-1 - Drainage from Clearwell Cleaning

Figure 3-2 - Residual from Clearwell Cleaning

SECTION 4. FINDINGS

There are a number of findings and observations that resulted from this study, including the following:

- A Purolite acrylic-based anion exchange resin seems to work significantly better in terms of reliable TOC removal at the Frisco plant than the ResinTech resin currently in use at the Skyco WTP. Therefore, the Purolite resin may be a good replacement for Skyco given the fact that the two plants have similar raw water characteristics.
- A large amount of chlorine decay historically had occurred through the clearwell. The removal of a large amount of debris from the clearwell drain line may reduce DBP formation in the future.
- There are significant physical and process limitations within the plant that may contribute to the elevated DBPs and less effective anion resin performance. Poor backwash during extended periods in the life of the anion exchange resins may have inadvertently occurred as a result of malfunctioning control valves. This may have been a major factor associated with the possible degraded condition and performance of these resins.
- Bromide seems to be a major contributor to the DBP formation from the Skyco WTP.

Based on the performance of the Frisco WTP in terms of TOC removal as compared to the Skyco WTP, it appears that the type of resin being utilized at the Frisco WTP, an acrylic resin, is much more appropriate for removing the TOC from the Dare County groundwater. The ResinTech resin utilized at the Skyco WTP is a styrenic resin which is characterized as having very good TOC removal capabilities, but does not release the organics very well during regeneration, reducing the overall service life of the resin. In addition, the styrenic resins tend to be relatively fragile and can break up generating a large amount of fine particles, thereby increasing the pressure loss across the vessels and the amount of backwash/regeneration flow required.

Since the debris had been removed from the clearwell, the chlorine demand across the clearwell may be reduced and this may reduce chlorine costs to some extent. Additionally, it should reduce the DBP formation as well. However, since the TOC removal across the resin is still less than optimal, there may be issues with TTHM levels in the distribution system. Careful monitoring will be required as well as regular future maintenance of the clearwell to ensure that debris does not build up in the future.

Due to some of the design issues with this facility noted previously (i.e. access to the vessels for effective maintenance, bypass flow which may allow iron to enter the anion resin vessels, etc.), there is the potential that even with the replacement of resin, the resin may not perform optimally and the life of the resin may be adversely

impacted. It is recommended that resin in one vessel be replaced with the Purolite acrylic resin of the type that is being used at the Frisco WTP and that this vessel be used as a pilot column for assessing the functionality of the anion exchange system following a resin replacement. County staff should monitor this performance and use this information as a basis for proceeding further.

Bromide seems to be a major component of the TTHMs that are being formed. As shown in Figure 4-1 and Figure 4-2, the bromide portion of the TTHMs in the finished water is a large portion of the total. In addition, as shown in Figure 4-3 and Figure 4-4, this is also the case with the HAA5s, although the total concentration of HAA5s don't seem to be as major of a concern. Bromide is an issue in terms of DBP formation as it is relatively heavy in terms of ug/L as compared to the chlorinated fractions of DBP. Therefore, a small amount of bromide can result in relatively large amounts of DBPs.

The bromide at the Skyco WTP is likely to be from one of two sources. First, the raw water could have bromide present. The County does not regularly test for bromide in the well supply. Based on a single sample taken during this study, the bromide appears to be less than 0.5 mg/L, which was the detection limit for the laboratory conducting the analyses. However, this is too high of a detection limit considering the levels found in the DBPs. It is recommended that bromide testing be performed with a new laboratory that has detection limits of 0.05 mg/L or less.

The other potential source is bromide that may be present in the salt used for the brine regenerant. Solar (or sea) salt, which is the most common and cost effective salt available, can contain levels of bromide. Rock salt, which can be significantly more expensive does not have bromide present. Therefore, if no bromide is found in the raw water, yet brominated DBPs are still being formed, the County could consider switching to a rock-based salt for the regenerant; however, the high cost for lower bromide salt may affect this decision.

The County should request the bromide content of the salt from the current supplier. Another way to help determine if the salt is a culprit may be to compare the DBP formation of brominated DBPs at the Frisco WTP, which one would assume utilizes the same salt for a regenerant.

Figure 4-1 – TTHM Fractional Breakdown – Manteo Meter

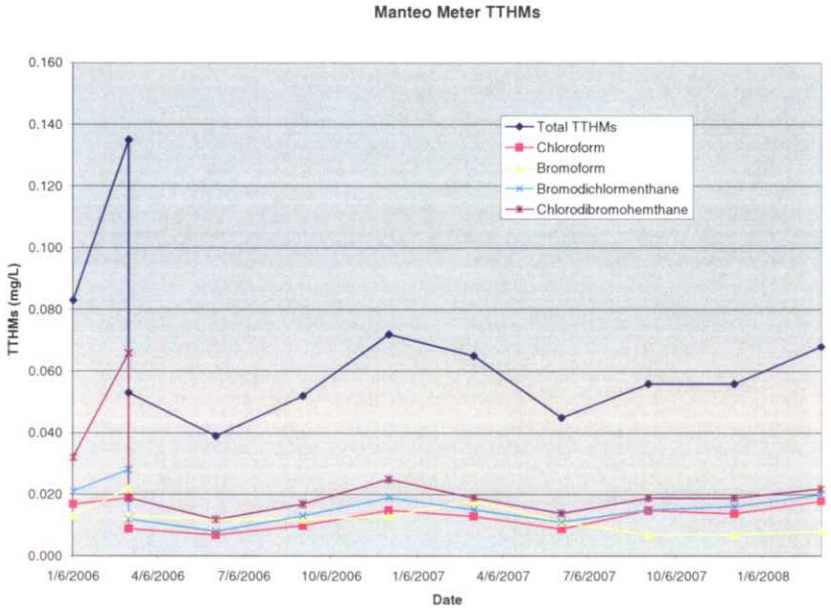


Figure 4-2 – TTHM Fractional Breakdown – Dare County Detention Center

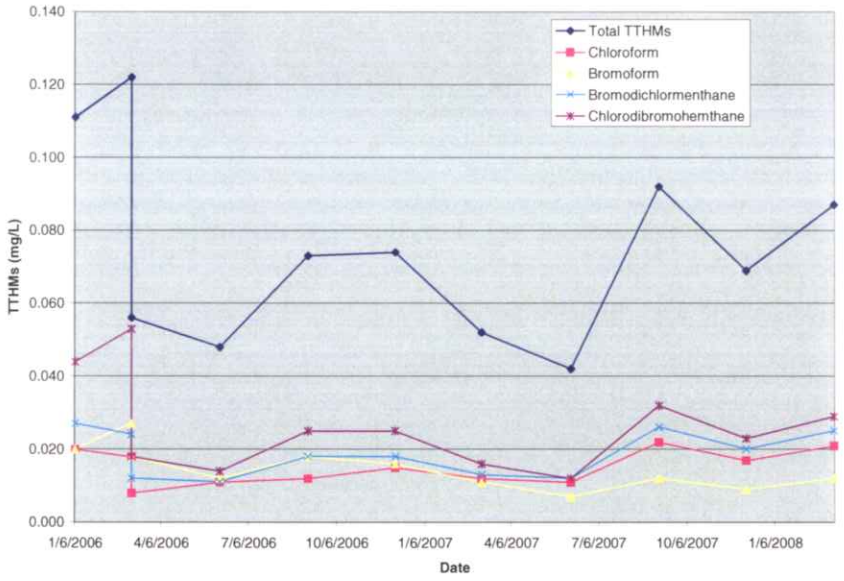


Figure 4-3 - HAA5 Fractional Breakdowns - Manteo Meter

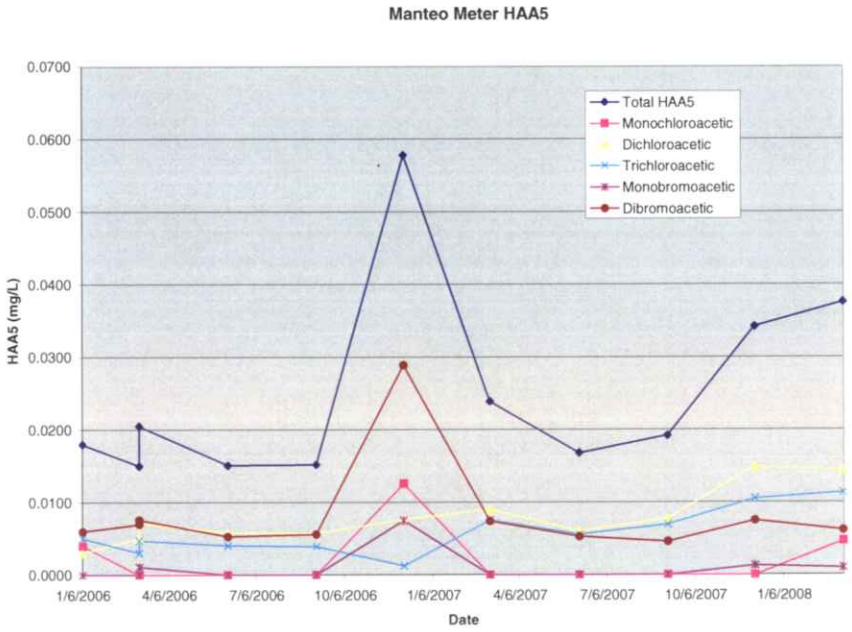
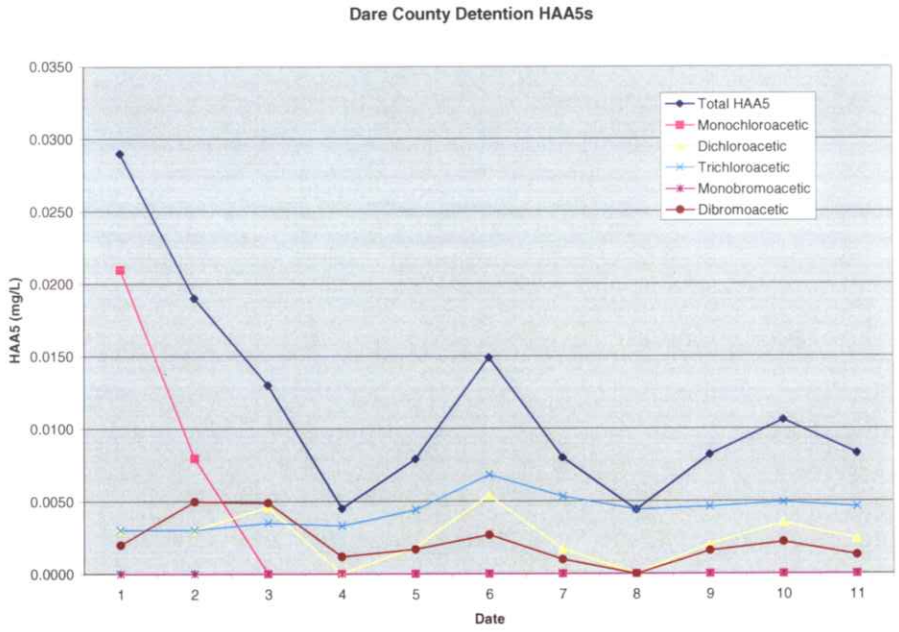


Figure 4-4 - HAA5 Fractional Breakdowns - Dare County Detention Center



Bromide may be somewhat difficult to remove, but an effective combination anion resin and regenerant salt may help. Further reduction of TOC with a new anionic resin would help as well.

SECTION 5. POTENTIAL IMPROVEMENTS

There are a number of potential improvements that could be made to Skyco WTP. However, with the limits of this study, each potential improvement may have limitations due to other factors. Table 4 summarizes some potential improvements, their benefit and potential limitations for long-term success.

Table 4 - Potential Skyco WTP Improvements

Suggestion	Benefits	Limitations
Add VFDs to the well pumps	• Much better control of withdrawals from the wells • Much better flow/pressure control to the plant. • Reduced operating costs	• Capital Cost
Modify/Replace Anion Exchange Vessels	• **Improve TOC and DBP precursor removal** • **Improve physical limitations and vessel access/maintenance**	• **Significant Cost** • **How much TOC removal is really required??**
Bypass Anion Exchange Vessels for trial period to see what TTHM's are forming in the system.	• Are the Vessels actually providing adequate treatment as intended? • Other Dare County WTP on similar wells doesn't require TOC removal • With clearwell clean, does DBP formation reduce adequately? • Reduces operating costs	• If TOC/DBP removal is required, will there be compliance issues?
Partial Bypass of Anion Exchange Vessels	• **Reduce fouling of anion resin** • **Increase life of resin** • **Reduce backwashing requirements**	• **Finished water TOC may increase slightly** • **Need SCADA control of valves and tie to influent TOC**
Replace/Modify Softener BW 3-way Valve	• Allow better operation when softeners are in backwash mode. • May reduce iron fouling of anion resin	• Cost • Iron may not be excessively fouling the anion resin • Test resin iron and other foulants
Replace the existing ResinTech resin with Purolite or other resin (Pilot testing of one vessel initially)	• **May improve TOC removal.** • **May be less susceptible to degradation based on experience at the Cape Hatteras WTP.** • **County staff familiar with Purolite**	• **Benefits and issues uncertain until pilot testing is complete.**
Increased SCADA control	• Improved control of well pumps and other elements from control room. • Improved system reliability	• Cost • Doesn't change/improve treatment process

Suggestion	Benefits	Limitations
Utilize different regenerent brine or regenerant.	• Brine may be a source of bromide. • Brominated THMs provide a great portion of the TTHMs • Sodium bicarbonate may be an alternative regenerant.	• Cost for high quality low bromide brine is high. • Bromide still could be in raw water. Detection limit was only 0.5 mg/L.
Develop Operation & Maintenance Plan	• Help operators better understand the process • Reduce potential future operating issues • Optimize complex process	• Time to develop

SECTION 6. RECOMMENDATIONS

Based on the available options, we have proposed the following approach to help improve the performance of the Skyco WTP.

1. Replace the existing resin in one anion exchange vessel with a PuroLite resin, or another acrylic resin with lower water content, similar to what is being utilized at the Frisco WTP. Perform a pilot test with this configuration to assess TOC removal, regeneration requirements and overall operating attributes. The gravel bed in the vessel should also be replaced at this time. Inspect the inside of the vessels during the replacement of the resin and determine the overall physical condition. Inspection should include spark testing of the liner and functional testing of backwash lateral distribution.
2. Consider replacing the resin in the remaining anion exchange vessels pending the outcome of the pilot test
3. Provide dechlorination facilities for the backwash water supply to both the cation softener and anion reactor vessels.
4. Reduce bypass around the softeners during periods of softener backwashing. Continue the existing operational initiatives that have proven successful in this area of plant operation.
5. Add VFDs with SCADA control on all Skyco WTP well pumps to provide turndown when softener vessels enter a backwash.
6. Evaluate salt utilized for brine regenerant for the presence of bromide. Utilize a different salt if appropriate and cost effective.
7. Increase raw water bromide sampling frequency and have analysis conducted with a detection limit of 0.05 mg/L.

In addition, the County should consider modifying other physical limitations of the facility to ensure the longevity of the resin. Should raw water bromide be a major contributor to the DBP formation, removal via a membrane process may be required in the future, especially in the event DBP compliance levels become more stringent.