DAF Pilot Study for Algae and DBP Reduction

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ABSTRACT: *A pilot study of dissolved air flotation clarification (DAF) with mixed media filtration was conducted at the Norwich Public Utilities Stony Brook WTP for the removal of disinfection byproducts and algae in the late summer of 2013. A variety of coagulants and flow rates were studied. DAF showed outstanding algae removal in excess of 90 percent with all coagulants. DBP removal varied by coagulant with ferric chloride and high doses of alum achieving the best results.*

Introduction

The Norwich Public Utilities' (NPU) Stony Brook Water Treatment Plant (WTP) is a 4.0 million gallon per day (mgd) plant built in 1996 consisting of two Infilco Degremont, Inc. (IDI) Advent package treatment units that are each rated for 2.0 mgd. The IDI Advent treatment units each consist of a non-buoyant media upflow clarifier with a maximum loading rate of 10 gallons per minute per square foot (gpm/sf) and multi-media filters with a rated capacity of 5 gpm/sf. Chemicals used at the plant over the years include a cationic polymer, alum, aluminum chlorohydrate (ACH), caustic soda, polyphosphate, and chlorine. Mixing is provided by an inline static mixer.

Both clarifiers at the Stony Brook WTP have experienced equipment failures over the years including plugging and channeling of the non-buoyant media and uneven distribution of backwash air and water flows due to plugging. The non-buoyant media has been replaced in each treatment unit and additional work on the underdrains and air/water inlet nozzles has been performed. In 2010, the plant was shut down for several months as a result of a green algae bloom in the Stony Brook Reservoir that caused severe plugging of the clarifier media. At that time, the primary coagulant at the plant was alum. Jar tests and online trials with various coagulants showed that ACH performed relatively well in combination with a cationic polymer. NPU changed their treatment to ACH and the cationic polymer at dosages of approximately 5 to 6 milligrams per liter (mg/L) and 3.0 mg/L respectively in the spring of 2011 and returned the plant to service. The maximum flow through the plant was 2.5 mgd, subsequent to the change in coagulant.

As a result of a pilot study performed at Stony Brook Reservoir in the early 1990s, buoyant clarifier media was selected as the preferred alternative. Subsequent pilot studies found that both buoyant and non-buoyant media were effective and both clarifier systems were allowed in bidding for construction of the plant. There are many package plants with buoyant media in New England and there are several cases across the country where clarifiers with non-buoyant media have been retrofitted to buoyant media. With the goal of improving treatment at the Stony Brook WTP and restoring capacity, NPU applied to the Connecticut Department of Public Health (DPH) for Drinking Water State Revolving Fund (SRF) funding for the replacement of the non-buoyant media clarifiers at the Stony Brook WTP with buoyant media in December of 2011. Based on this application, the project was deemed eligible for funding. In November 2012, NPU began the Qualifications Based Selection (QBS) Process to select an engineering firm to perform the design of the proposed buoyant media project.

In reviewing the Request for Qualifications (RFQ) issued by NPU for the buoyant media conversion project, there were a number of concerns. The first concern was compliance with the Stage 2 Disinfectant/Disinfection By-Products Rule (D/DBPR). A study of the Taftville/Occum service area of the Norwich system in August 2012 revealed that the Total Trihalomethane Formation Potential (TTHMFP) concentration in the treated water from the Stony Brook WTP was 177.2 micrograms per liter (ug/l). Although NPU had been in compliance with the Stage 1 D/DBPR to this point, the new Stage 2 D/DBPR was due to take effect for systems the size of NPU in 2013. Under Stage 2, compliance would no longer be measured by a system wide average of the running annual average of data collection points but rather would be measured by a locational running annual average of sample points likely to have the highest levels of disinfection by-products. Monitoring for Stage 2 of the D/DBPR was set to begin in October 2013 for NPU. The ability of NPU to comply with these new rules was uncertain.

Second, the preferred treatment for reducing disinfection by-products is enhanced coagulation. Even with a conversion to buoyant media, the increased solids loading onto the clarifiers caused by enhanced coagulation would result in shorter run times and reduced capacity.

Third, the detention time through the existing treatment process was very short. The detention time from the static mixer to the entry point to the clarifiers at a flow rate of 2.5 mgd was only 20 to 26 seconds. At the design flow of 4.0 mgd, the detention time was only 12 to 16 seconds. This detention time is not sufficient for good floc formation which in turn will allow the clarifiers to perform properly. Additionally, the quality of mixing provided by a static mixer is not ideal, which exacerbates the problem of poor floc formation. The RFQ for the buoyant media project did not address these problems.

Lastly, the total algae counts in 2010 approached 10,000 cells per milliliter. Although the green algae (Teilingia) has not recurred at similar levels, other algae such as Synedra and Tabellaria have been found as recently as 2013 at comparable high levels. The loading onto the clarifiers from a sustained algae bloom again resulted in shortened runs, increased spent washwater, and reduced capacity.

The addition of rapid mixing, flocculation and dissolved air flotation (DAF) ahead of the existing Advent treatment units was proposed instead of the conversion of the non-buoyant media to buoyant media. By doing so, the water treatment plant could effectively reduce disinfection by-products (DBPs) through enhanced coagulation, improve the quality of floc formation by increasing coagulant detention time with better mixing, and address the increased clarifier loading caused by high algae levels. DAF has a demonstrated ability to handle high solids loads caused by enhanced coagulation or high algae counts without the clogging and shortened runs associated with media clarifiers.

The budget for the conversion of the non-buoyant clarifier media to buoyant media was just over $1.8 million. It was estimated that the addition of package DAF treatment units ahead of the IDI Advent treatment units in a pre-engineered steel building addition, along with other improvements recommended in the RFQ, would be $3.0 million including engineering and a single season pilot study. There are at least three manufacturers of package DAF clarifiers with rapid mixing and flocculation: Infilco Degremont, Inc. of Richmond, VA, Leopold of Zelienople, PA and The Roberts Filter Group of Darby, PA.

NPU filed a Project Rollover Update Form with DPH on January 30, 2013 to roll the project over into the next funding cycle as the selection of an engineering firm and completion of design could not be completed by June 30, 2013. Based on recommendations, NPU modified the project to eliminate the replacement of the non-buoyant media in the clarifiers with buoyant media and replace it with the addition of dissolved air flotation.

Advanced Arrangements

To the extent possible, arrangements for pilot testing equipment were made in advance of receiving authorization to proceed. An IDI DAF pilot treatment unit was moved on-site and the necessary influent, effluent and waste piping and electrical connections made within three weeks. NPU applied for a temporary discharge permit for the plant effluent, which was received prior to start-up of the pilot plant. Figure No. 1 shows the location and piping for the pilot plant.

A pilot treatment plan was quickly developed that set the procedures for jar testing and pilot testing, along with the water quality analyses to be conducted during testing. There were no provisions made for chlorinating the water used for the jar testing or the pilot treatment study. Therefore, a laboratory was selected that was capable of correctly dosing the samples with chlorine and holding them for the required length of time to complete the formation of disinfection byproducts prior to analysis. A local laboratory was found in Dayville, CT, Premier Laboratory, Inc.* that was only 30 miles from the Stony Brook WTP, a reasonable driving distance for delivery of the samples.

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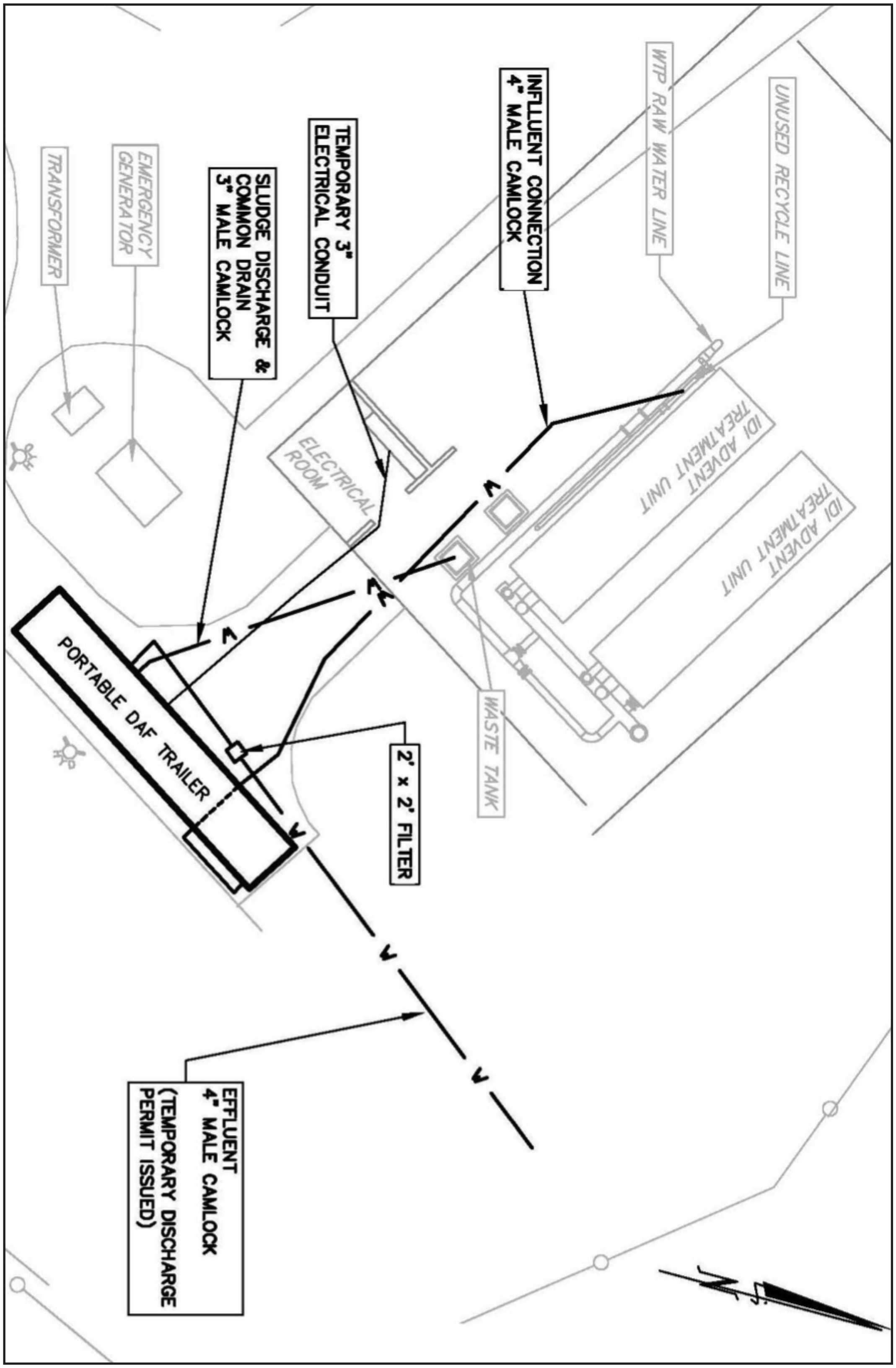
*Premier has since been purchased by Microbac Laboratories, Inc. of Pittsburg, PA

Figure No. 1
DAF Pilot Plant Piping Schematic



Bench Scale Jar Testing

In advance of and concurrent with the pilot treatment study, bench scale jar testing was conducted to evaluate various coagulants and other treatment chemicals and dosage rates for effectiveness in removing total and dissolved organic carbon (TOC, DOC), UV 254, and disinfection byproducts.

Bench scale jar test studies at the Stony Brook WTP began on August 19, 2013 and were conducted intermittently until September 30, 2013. Four separate coagulant combinations were studied during the jar tests. They were:
- Aluminum sulfate (alum) at dosages of 10 to 50 mg/L.
- Aluminum chlorohydrate (ACH) at dosages of 2.3 to 13.8 mg/L
- Alum and sodium aluminate (NaAlO2) at dosages of 15 mg/L Alum/7.5 mg/L NaAlO2 to 30mg/L Alum/15 mg/L NaAlO2
- Ferric Sulfate (Ferric) at dosages of 10 mg/L to 40 mg/L
- Ferric at a dosage of 25 mg/L with powdered activated carbon (PAC) added at 5 mg/L, 10 mg/L and 20 mg/L

The table on the next page summarizes raw water quality at the Stony Brook WTP.

Table No. 1
Average Raw Water Quality Summary

Parameter	Units	MCL	2010	2011	2012	2013	Average 2010-2013	Min. (2010-2013)	Max. (2010-2013)
Iron	mg/L	0.3*	Not Tested	0.16	0.15	0.14	0.15	0.039	0.65
Manganese	mg/L	0.05*	Not Tested	0.034	0.016	0.036	0.032	0.004	0.28
Total Organic Carbon	mg/L	None	4.22	3.95	3.50	3.58	3.78	2.75	5.34
Alkalinity	mg/L as CaCo3	None	4.82	5.82	7.46	7.14	6.34	1.00	10.0
Turbidity	mg/L	None	1.22	0.93	0.98	0.94	1.01	0.44	2.40
Color	C.U.	N/A	21.8	25.5	24.4	22.6	23.7	15.0	45.0
pH	-	6.5-8.5	6.82	6.80	6.90	6.83	6.85	6.20	7.70

*Secondary Standard

In the course of jar testing, samples of mixed water (raw water with the addition of coagulation treatment chemicals prior to clarification) from the Stony Brook WTP were collected, mixed in the jars, and analyzed following the same procedures as the jars dosed with the various coagulants.

In order to promote the maximum potential formation of total trihalomethanes (TTHM-max) and total haloacetic acids (THAA5-max)in raw water, the lab dosed the raw water with high doses of chlorine (12 mg/L), held the samples for seven days as required by Standard Methods, measured residual chlorine to ensure there was still a residual and the DPB formation was complete and then measured the levels of DPB in the samples.

Stony Brook WTP filtered water and pilot plant filtered water were alo tested for Simulated Distribution System (SDS) TTHM and SDS THAA. The SDS samples were dosed with chlorine, held for seven days to match the maximum detention time in the NPU distribution system and then analyzed. Chlorine dosage was set to achieve a residual in the samples at the end of seven days between 1.0 to 2.0 mg/L to make sure the formation of DBPs was complete.

For total organic carbon removal, total trihalomethane (TTHM) removal and total haloacetic acid (THAA) removal, ferric chloride at a dosage of 20 mg/L performed best in the jars with nearly 60 percent TOC removal (Figure No. 2), over 70 percent TTHM removal (Figure No. 3) and over 85 percent THAA removal (Figure No. 4). Alum at a dosage of 40 mg/L performed nearly as well as ferric for DBP removal, although not quite as well for TOC removal. All the coagulants studied performed better in the jars than the mixed water from the Stony Brook WTP.

Figure No. 2
Total Organic Carbon Percent Removal

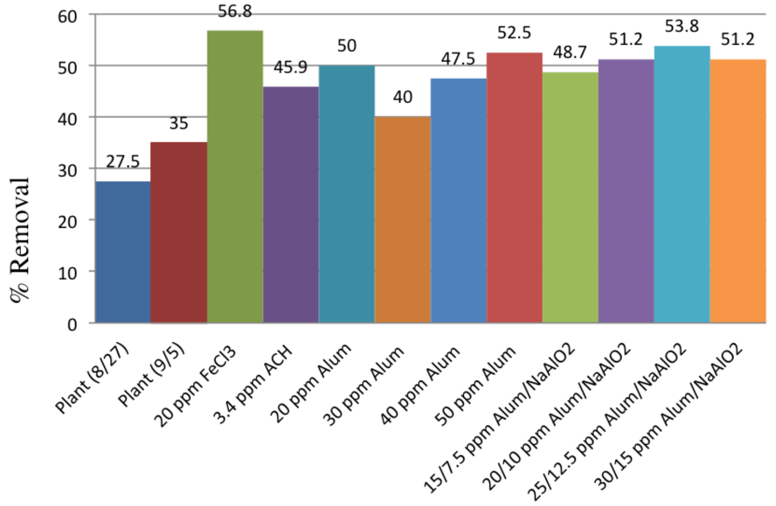


Figure No. 3
TTHM Percent Removal

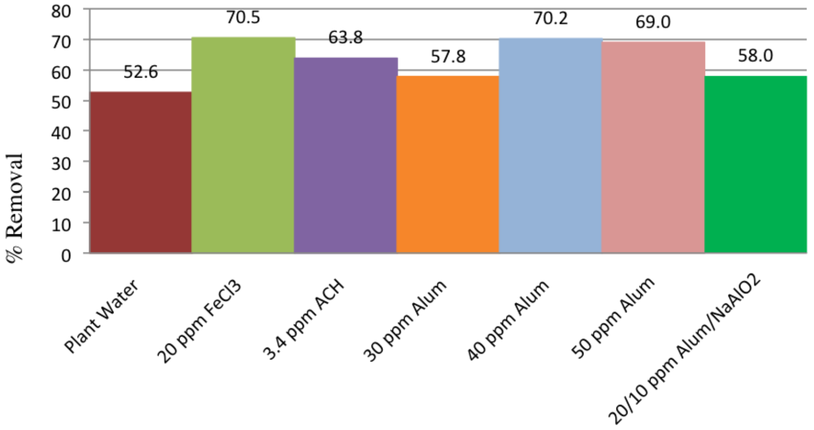
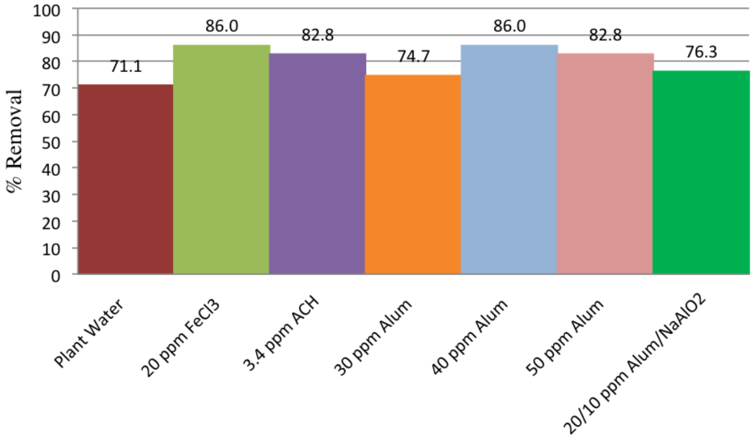


Figure No. 4
HAA Percent Removal



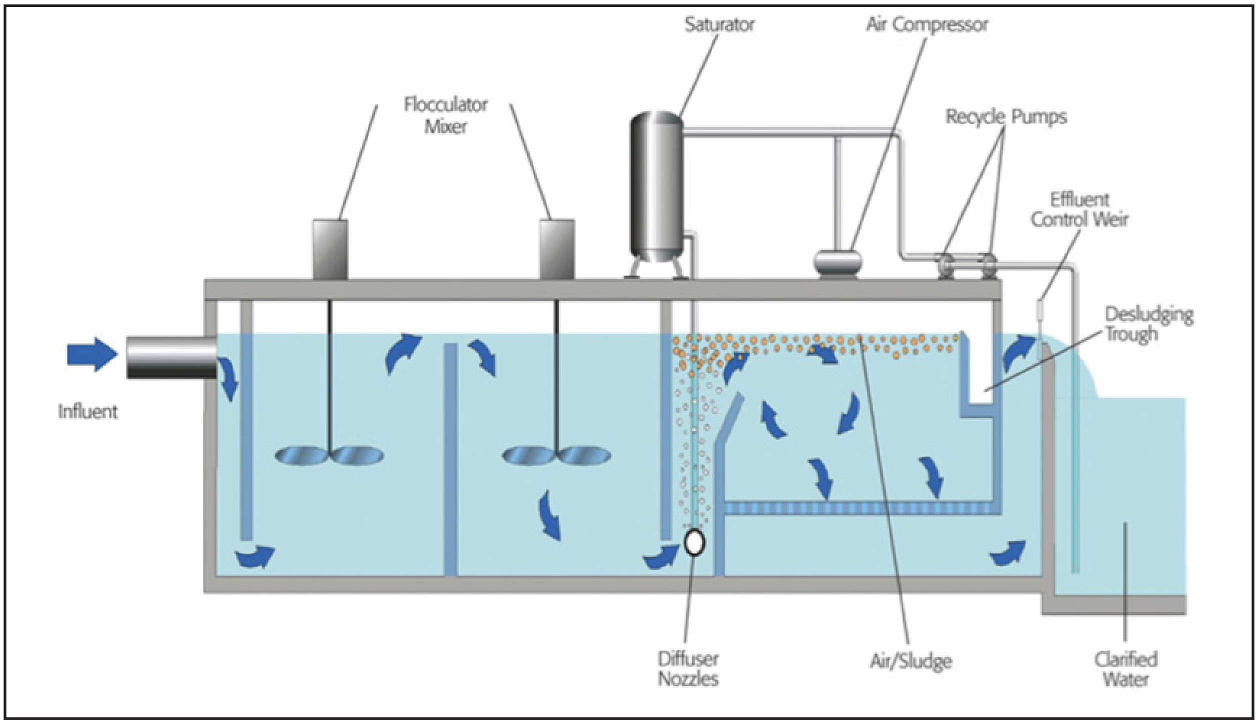
Samples from the jars were analyzed to determine if the addition of powdered activated carbon (PAC) would further reduce TOC and disinfection byproducts compared to the addition of coagulant alone. For the PAC jars, ferric chloride was used as the coagulant. A dose of 25 mg/L of ferric chloride was used in all jars with the addition of 0 mg/L, 5 mg/L, 10 mg/L and 20 mg/L of PAC.

The results from this set of jar testing showed no material improvement in DBP removal from the addition of PAC and worse performance for TOC removal when compared to ferric chloride alone. Accordingly, PAC was not evaluated during the pilot treatment study.

DAF Pilot Plant and Filter Set Up

The IDI AquaDAF® pilot plant that was delivered to the Stony Brook WTP consisted of a rapid mix chamber, two flocculator chambers with variable speed mixers, and the flotation chamber. A schematic drawing is provided in Figure No. 5 below.

Figure No. 5
DAF Pilot Unit Schematic



The DAF pilot plant was installed in a climate controlled trailer with all equipment required to operate the unit including chemical feed pumps and storage tanks, recycle pump, saturator vessel, air compressor, turbidimeters, pH analyzers, flow meter and flow control valve, data logger, and PLC control panel.

The pilot plant began operation on August 29, 2013 using alum as a primary coagulant. Initial test runs were conducted to establish an appropriate chemical dose rate and pH to produce a high quality DAF effluent.

Arrangements were made with Roberts Services, Inc. for delivery of a pilot filter to the site on September 3, 2013. Media arrived two days later and was installed to mirror the media insatallation in the existing filters at the Stony Brook WTP. Manometers were added to the pilot filter to measure headloss through the media. Terminal headloss for filter runs during pilot testing was set at 60 inches based on submergence measured in the Stony Brook WTP filters.

Flow through the pilot filter was set using manual ball valves and rotameters. DAF effluent water was pumped to the top of the filter and discharged through an overflow approximately 120 inches above the top of the filter media, setting a constant head over the filter.

DAF Pilot Treatment Study

The pilot study was conducted to determine the effectiveness of rapid mixing, flocculation and dissolved air flotation (DAF) clarification installed prior to the existing IDI Advent treatment units at Stony Brook. The goals that were expected to be achieved by adding these unit processes were:

- Increase plant detention time allowing full floc formation ahead of clarification;
- Improve mixing, resulting in better floc formation;
- Improve the removal of disinfection byproducts through enhanced coagulation;
- Utilize a technology (DAF) that has proven to be the most effective in removing algae without lysing cells and spilling their contents into the water, thereby increasing total organics concentrations;
- Provide a more concentrated waste residual than upflow clarification or sedimentation; thereby reducing sludge volumes generated by enhanced coagulation;
- Produce excellent clarification effluent quality, and
- Increase filter run times.

Raw water quality over the course of the study was very consistent. TOC levels were 3.8 - 4.0 mg/L. Raw water temperatures averaged 23.4° C in September and were at 20° C at the conclusion of the study in early October. DBP levels can be found in Table No. 2 below.

Table No. 2
Maximum Raw Water DBPs

Date	Cl2 Dose mg/L	Cl2 Res mg/L	TTHMmax ug/L	THAAmax ug/L
8/28/2013	12.0	4.6	189.3	349.3
9/16/2013	12.0	4.1	230.0	357.1
9/24/2013	12.0	5.5	180.0	397.6
9/29/2013	12.0	4.6	191.0	339.8
10/8/2013	12.0	4.2	212.0	358.6
Average	**12.0**	**4.6**	**200.5**	**360.5**

Water quality from the Stony Brook WTP was used as a control during the pilot study. TOC in the WTP filtered water was measured at 2.0 – 2.3 mg/L over the course of the pilot study. DBP results are shown in Table No. 3 below.

Table No. 3
Stony Brook WTP Filtered Water SDS DBPs

Date	Cl2 Dose mg/L	Cl2 Res mg/L	SDS TTHM ug/L	SDS THAA ug/L
9/12/2013	5.0	1.9	75.1	
9/16/2013	4.0	1.6	77.7	77.2
9/29/2013	4.0	1.5	69.8	71.2
10/2/2013	4.0	1.7	77.4	
10/4/2013	4.0	1.8	82.2	
10/8/2013	4.0	1.6	81.2	74.1
Average	**4.2**	**1.7**	**77.2**	**74.2**

The first pilot run began on September 9, 2013 using alum at 25 mg/L and a loading rate of 10 gpm/sf. The loading rate was set to match the loading rate through the Stony Brook WTP, which was 1,100 gpm through a single IDI Advent unit with a design flow of 1,200 gpm. The pilot filter flow was set at 4.2 gpm/sf to match the WTP.

Due to Stony Brook WTP operational constraints, each day's pilot plant operations experienced a short shut down of approximately 4 hours.

Alum Treatment Runs

The initial alum test run was set at a DAF loading rate of 10 gpm/sf with a corresponding filtration rate of 4.2 gpm/sf. Over the course of the run, alum was fed at 25 mg/L with pH adjustment with 7 mg/L caustic soda to a mixed water pH of 6.2. Average DAF effluent turbidity during the run was 0.24 NTU. Filtered water turbidity was maintained in the range of 0.05 to 0.08 NTU. The filter run was projected to reach terminal headloss of 60 inches at 76 hours.

Samples were collected from raw water, filtered water from the existing Stony Brook WTP and filtered water from the pilot plant. The results are shown in Table No. 4. The pilot plant filtered water showed an increase in the removal of TOC, DOC, SUVA and SDS TTHM when compared to the Stony Brook WTP.

Table No. 4
Water Quality – 25 mg/L Alum, 10 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	SDS TTHM ug/L
Raw Water	3.8	4.0	2.6	
Plant Filter Effluent	2.1	2.4	1.5	75.1
Pilot Filter Effluent	1.9	2.1	1.3	63.0
Pilot/Plant % Reduction	9.5	12.5	13.3	16.0

A second run was conducted at 12 gpm/sf (Design Flow) DAF loading rate with a corresponding filtration rate of 5.0 gpm/sf. The alum dosage was increased to 30 mg/L to maintain DAF effluent turbidity below 0.3 NTU. Filtered water turbidity was maintained in the range of 0.05 to 0.1 NTU. The filter reached terminal headloss at 46.5 hours.

The DAF pilot study plan called for more extensive testing at the higher flow rates for all the coagulants studied. The results are shown in Table No. 5. Again the pilot plant filtered water showed increased reductions in TOC and DOC and THMs. THAA was significantly reduced as well, although SUVA was the same for both the Stony Brook WTP and the pilot plant.

Table No. 5
Water Quality – 30 mg/L Alum, 12 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	TTHM max ug/L	THAAmax ug/L	SDS TTHM ug/L	SDS THAA ug/L
Raw Water	3.8	3.8	2.8	230.0	357.1		
DAF Effluent				89.6	105.9		
Plant Filter Effluent	2.1	2.2	1.5	91.1	96.4	77.7	77.2
Pilot Filter Effluent	1.8	1.9	1.5	75.5	78.7	68.1	58.2
Pilot/Plant % Reduction	14.2	13.6	0	17.1	18.3	12.3	24.6

Algae samples collected from the DAF effluent during the alum treatment runs showed 98.7 percent removal at 10 gpm/sf and 93.6 percent removal at 12 gpm/sf when compared to raw water.

Sludge samples collected during the alum runs had a solids content of 3.6 percent and 2.5 percent at 10 gpm/sf and 12 gpm/sf, respectively. The total volume of wet sludge predicted to be produced per million gallons of water treated at an alum dosage rate of 30 mg/L is approximately 50 cubic feet (cf).

Alum/Sodium Aluminate Treatment Runs

The initial alum/sodium aluminate test run was set at 10 gpm/sf DAF loading rate and 4.2 gpm/sf filtration rate. Dosage rates during the run were 20 mg/L alum and 10 mg/L sodium aluminate.

DAF effluent turbidity was excellent at 0.2 NTU and the filter run was projected at 71 hours. However, color removal was poor with filtered water color in the range of 10-12. The sample collected from the Stony Brook WTP filter effluent was found to contain a low level of chlorine upon delivery to the laboratory and the SDS TTHM result for this sample was almost 50 percent higher than the average result for all other samples collected at the plant. The sample results are shown in Table No. 6.

Table No. 6
Water Quality–20 mg/L Alum, 10 mg/L NaAlO2, 10 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	SDS TTHM ug/L
Raw Water	3.8	3.5	2.8	
Plant Filter Effluent*	2.0	2.1	1.3	112.1
Pilot Filter Effluent	1.9	2.0	1.4	70.5
Pilot/Plant % Reduction	5.0	4.8	(7.7)	40.6

* Invalidated

No explanation for the chlorine contamination in the plant filter effluent could be found. Given the results that were out of range when compared to samples collected from the same location throughout the pilot study, the sample was invalidated. Substituting the average values for TOC, DOC, SUVA and SDS TTHM for the plant filter effluent gives the results shown in Table No. 6-A.

Table No. 6-A
Water Quality–20 mg/L Alum, 10 mg/L NaAlO2, 10 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	SDS TTHM ug/L
Raw Water	3.8	3.5	2.8	
Average Plant Filter Effluent	2.2	2.2	1.5	77.2
Pilot Filter Effluent	1.9	2.0	1.4	70.5
Pilot/Plant % Reduction	13.6	9.1	6.7	8.7

Despite the limited data on alum and sodium aluminate treatment, the information that was available showed that this was not a treatment of choice for the Stony Brook WTP. The results in Table No. 6-A are not as good as predicted by the jar tests or as good as alum alone. The high color levels in the pilot plant filtered water are also a concern. Sodium aluminate can be a difficult chemical to handle with plugging of chemical feeders and feed lines a frequent problem. For these reasons, sodium aluminate was not considered further for evaluation at Stony Brook.

Aluminum Chlorohydrate (ACH) Treatment Run

ACH was initially tried in the DAF pilot plant at feed rates ranging from 5 – 25 mg/L. A proper float could not be established at any dosage of ACH and effluent turbidity from the DAF was up around 3 NTU. ACH was discontinued pending additional jar testing and the DAF was converted to alum and sodium aluminate as coagulants.

Subsequent jar testing showed that ACH produced good, settleable floc at a dosage of 3 mg/L but not at any other dosages either higher or lower. An attempt was made to improve flocculation at 5 mg/L by the addition of various dosages of an anionic polymer but no improvement was noted.

Based on the jar test results, the DAF test run was started up using 3 mg/L ACH at a loading rate of 6 gpm/sf. A float was established and good effluent turbidity results (0.23 NTU) were noted. The pilot plant ran overnight at this rate, and then was increased to 8 gpm/sf the next morning. After a couple of hours at 8 gpm/sf, the plant flow was increased to 10 gpm/sf and a pilot run begun.

At 10 gpm/sf, the DAF effluent turbidity using ACH was consistently above 0.4 NTU, the highest levels of any of the coagulants tested. Accordingly, the filter run was short at 38 hours. Both alum and alum/sodium aluminate had filter runs longer than 70 hours at 10 gpm/sf.

Samples were collected with the results shown in Table No. 7.

Table No. 7
Water Quality – 3 mg/L ACH, 10 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	SDS TTHM ug/L
Raw Water	3.7	3.3	3.0	
Plant Filter Effluent	2.2	2.2	-	77.4
Pilot Filter Effluent	2.0	1.9	1.2	71.2
Pilot/Plant % Reduction	9.1	13.6	-	8.0

The ACH floc was delicate and easily sheared. The reduction in SDS TTHM of 8.0 percent seen in the DAF pilot compared to the existing plant was considerably lower than the reduction predicted by the jar tests.

Given the poor filter run and high DAF effluent turbidity, ACH was not piloted at the 12 gpm/sf rate.

Algae samples showed 98.9 percent removal of cells through the DAF process. Samples collected at the same time from the Stony Brook WTP clarifier effluent showed 33.7 percent removal of cells.

A sample from the ACH run showed a solids concentration of sludge from the DAF of 4.2 percent, the highest level measured for any coagulant. The volume of wet sludge produced by the process was predicted to be 27 cf for every million gallons of water treated.

Ferric Chloride Treatment Runs

Ferric chloride at a dosage of 20 mg/L was started in the DAF pilot plant at 10 gpm/sf. Initial effluent turbidity from the DAF was above 0.3 NTU. A change in the mixing speeds of the flocculators to add more energy was made that improved flocculation and lowered effluent turbidity to below 0.3 NTU. The rate of filter headloss also decreased. The filter reached terminal headloss at 50 hours but likely would have run longer had the mixing speed adjustment been made at the start of the run.

Ferric chloride required about 50 percent more caustic soda to reach flocculation pH when compared to the same dose of alum.

Samples results are shown in Table No. 8.

Table No. 8
Water Quality – 20 mg/L Ferric Chloride, 10 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	SDS TTHM ug/L
Raw Water	3.8	3.6	2.6	
Plant Filter Effluent	2.2	2.1	0.81	82.2
Pilot Filter Effluent	1.5	1.6	0.69	65.9
Pilot/Plant % Reduction	31.8	23.8	14.8	19.8

The pilot run was repeated at a 12 gpm/sf DAF loading rate and 5 gpm/sf filtration rate, again using 20 mg/L of ferric chloride as coagulant. DAF effluent turbidity (0.24 NTU) showed very good results. The pilot filter reached terminal headloss after 44 hours run time. Sample results are shown in Table No. 9.

Table No. 9
Water Quality – 20 mg/L Ferric Chloride, 12 gpm/sf DAF LR

Sample Point	TOC mg/L	DOC mg/L	SUVA L/mg-m	TTHM max ug/L	THAAmax ug/L	SDS TTHM ug/L	SDS THAA ug/L
Raw Water	3.9	3.6	2.7	212.0	358.6		
DAF Effluent				84.5	87.7		
Plant Filter Effluent	2.1	2.0	1.5	93.1	101.4	81.2	74.1
Pilot Filter Effluent	1.5	1.5	1.4	68.7	71.0	54.1	54.1
Pilot/Plant % Reduction	28.6	25.0	6.7	26.2	30.0	33.4	27.0

Ferric chloride produced the best removal rates for TOC, TTHM and THAA with an average removal of 25 percent better than the existing Stony Brook WTP at design flow. These results are consistent with the results seen in the jar tests. However, a manganese sample collected from the filtered water during the 12 gpm/sf run showed a level of 0.027 mg/L. Manganese is a frequent low level contaminant found in ferric chloride. While the level seen in the filtered water is less than the secondary MCL for manganese of 0.05 mg/L, consistent manganese levels above 0.01 mg/L in water entering the distribution system can cause customer complaints of black specks in the water following system disruptions.

No samples were collected for algae during the ferric chloride runs. However, pilot experience from other locations demonstrates that similar results for algae removal can be expected from the DAF using ferric chloride as the other coagulants.

Sludge samples collected during the ferric chloride runs had a solids content of 3.1 percent and 3.4 percent at 10 gpm/sf and 12 gpm/sf, respectively. The total volume of wet sludge predicted to be produced per million gallons of water treated at a ferric chloride dosage rate of 20 mg/L is approximately 66 cf.

Alum or Ferric Chloride?

The DAF pilot study showed that DAF is effective for treating water from the Stony Brook Reservoir using either ferric chloride or alum as the primary coagulant. Ferric chloride produced the best reductions in organic compounds, including DBP precursors, when compared to the other coagulants tested. However, alum also performed well and the jar tests indicated that it could provide reductions in DBP precursors that were nearly identical to ferric chloride at a dosage of 40 mg/L. Given the variation in DBP precursor levels throughout the year in New England surface waters, it should only be necessary to feed alum at 40 mg/L during the summer months; maintaining lower dosages the rest of the year.

A comparison of alum and ferric chloride is provided in Table No. 10. Based on this comparison, Tata & Howard recommended that alum should be used as the primary coagulant with the conversion to DAF at the Stony brook WTP.

Table No. 10
Alum vs. Ferric Chloride

Alum	Ferric Chloride
Good overall reduction in disinfection by- products and TOC. May be able to achieve comparable DBP reduction as Ferric at higher dosage rates.	Best overall performance for reduction in disinfection byproducts and TOC.
Performed well over a wide variety of dosage rates.	Showed sensitivity to varying dosage rates, pH and flocculator mixing speeds.
Dosage rates will need to be adjusted over the course of the year to achieve best DBP removal.	Dosage rates should remain constant over the course of a year.
Lower chemical costs	Chemical costs approximately 50% higher than alum.
Lower sludge volume.	Sludge volume approximately 33% higher than alum.
No staining	Will cause staining on surfaces.
Alum does not contain significant levels of manganese. Filtered water during the alum run showed 0.0066 mg/L manganese (Raw water manganese was 0.027 mg/L).	Ferric chloride often contains significant levels of manganese. Filtered water during the ferric chloride run showed 0.027 mg/L manganese (Raw water manganese was 0.018 mg/L).
The Stony Brook WTP has operated with alum in the past. The operators are familiar with its handling and feeding.	NPU has limited experience with ferric chloride.

Conclusions and Recommendations

NPU had indentified the following issues with the existing treatment at the Stony Brook WTP:

- A lack of detention time that does not allow complete floc formation of coagulants prior to entry into the clarifiers.
- Poor mixing.
- Inability of the WTP to handle a significant algae bloom.
- Compliance with new Stage 2 Disinfectant/Disinfection By-Products Rule cannot be assured.
- The existing plant cannot handle the increased solids loading required by enhanced coagulation to remove organic compounds in the raw water including DBP precursors.
- The plant generates a very high amount of wastewater due to short filter runs and the need to air scour and wash the clarifier media frequently.

To address these issues, a pilot study was conducted to review the effectiveness of rapid mixing, flocculation and dissolved air flotation (DAF) clarification added ahead of the existing IDI Advent treatment units at Stony Brook. The goals that were expected to be achieved by adding these unit processes were:

- Increase plant detention time allowing full floc formation ahead of clarification;
- Improve mixing, resulting in better floc formation;
- Improve the removal of disinfection byproducts through enhanced coagulation;
- Utilize a technology (DAF) that has proven to be the most effective in removing algae without lysing cells and spilling their contents into the water, thereby increasing total organics concentrations;

- Provide a more concentrated waste residual than upflow clarification or sedimentation; thereby reducing sludge volumes generated by enhanced coagulation;
- Produce excellent clarification effluent quality, and
- Increase filter run times.

The intent of the pilot study was to treat warm water from the Stony Brook Reservoir when DBP precursors, TOC and algae were likely to be near the highest levels of the year. The project began in August and was completed the first week in October, meeting this objective.

The DAF pilot plant performed as expected. When compared to the existing Stony Brook WTP, the pilot plant clearly showed improved clarification, longer filter runs, better algae removal, a much more concentrated clarifier sludge and improved removal of TOC and DBP precursors.

The conversion to DAF treatment at the Stony Brook WTP is expected to decrease chemical costs by $2,700 and increase electric costs by $2,400. The converted plant is also expected to reduce the volume of waste discharged by 90 percent, although the overall mass of solids would be higher than at present.

The recommendations for the upgrade of the Stony Brook WTP based on the results of the pilot study are:

1. Two 2.0 mgd dissolved air flotation (DAF) package treatment units should be added to the treatment train ahead of the existing IDI Advent units.
2. Each DAF package treatment unit should include rapid mixing and two stage flocculation with variable speed mixers.
3. DAF loading rates at design flow should not exceed 12 gpm/sf. Filter loading rates at design flow should remain as current at 5 gpm/sf.
4. The non-buoyant media in the existing IDI Advent units should be removed. The media underdrains and filter nozzles should be examined to determine if they cause an unacceptable hydraulic restriction. Provisions for the periodic washdown of the clarifier portion of the IDI Advent unit, if they do not already exist, should be made.
5. Alum should be used as the primary coagulant at dosages ranging from 20 mg/L to 40 mg/L depending on raw water quality.
6. The coagulant chemical storage tank(s), feed pumps and chemical feed lines should be constructed of materials that are compatible with both alum and ferric chloride.
7. The amount of sodium hydroxide added as a pre-treatment chemical will increase by 4,000 gallons per year if alum is used as the primary coagulant. The size of the chemical storage tank and feed pumps should be examined accordingly.
8. Provisions should be made for adding an anionic or non-ionic polymer as an emulsion at dosages not to exceed 1.0 mg/L.
9. NPU should review plans for construction of lagoons at Stony Brook WTP in light of the 90 percent reduction in wastewater volume and increased mass of solids expected with conversion to DAF.

The conversion of the Stony Brook WTP to dissolved air flotation treatment is now in design.