Hampton Roads' innovative approach to managed aquifer recharge

Pilot test results confirmed by Hampton Roads Sanitation District prove that Granular Activated Carbon- and Reverse Osmosis-based treatment trains produce high quality water that exceeds drinking water standards. Authors **Tyler Nading**, **Larry Schimmoller**, and **Germano Salazar-Benites** explain the treatment processes, pilot tests, and the ways in which the SWIFT program could benefit the district's water resources.

The Hampton Roads Sanitation District (HRSD) Sustainable Water Initiative for Tomorrow (SWIFT) will add advanced water treatment (AWT) processes to treat wastewater treatment plant effluent to meet or exceed US Environmental Protection Agency (USEPA) primary drinking water standards. The treated water will then be used to recharge the Potomac Aquifer System (PAS). Withdrawals from this system have been occurring at an unsustainable rate, impacting the issuance of groundwater withdrawal permits, contributing to land subsidence in eastern Virginia, and increasing the aquifer's vulnerability to saltwater intrusion. The SWIFT program will not only enhance the sustainability of the region's long-term groundwater supply but also reduce the existing permitted nutrient load currently entering the sensitive Chesapeake Bay.

Feasibility assessment

The SWIFT program began with a feasibility assessment to identify potential treatment trains to meet drinking water quality standards. Three such trains were identified as viable candidates:

1. Flocculation/Sedimentation (Floc/Sed) – Ozone Oxidation – Biofiltration (BAF) – Granular Activated Carbon (GAC) Adsorption – Ultraviolet Disinfection (UVD) – Chlorine disinfection
2. Microfiltration (MF) – Reverse Osmosis (RO) – Ultraviolet Advanced Oxidation Process (UVAOP) – Chlorine disinfection
3. MF-Nanofiltration (NF) – UVAOP – Chlorine disinfection.

Each of the three viable treatment processes provides a multi-barrier approach to both pathogens and organics, which is critical to advanced treatment. Table 1 shows the Class IV-V cost estimates that were developed for a generic 75.7 million liter per day- (mld) AWT plant for each of the treatment trains to demonstrate the relative cost between the different options.

Pilot testing

HRSD pilot-tested both the GAC-based and RO-based trains at its York River Treatment Plant to ensure that each treatment process could produce water that exceeds drinking water standards and to compare the performance of the two treatment processes. The York River plant is one of the seven candidate treatment plants for AWT. The RO-based pilot train was operational from June 2016 to December 2016, while the GAC-based pilot train was operational from July 2016 to October 2017, providing significant time for side-by-side comparison of the different treatment trains treating the same source water. Table 2 provides the fundamental design criteria used during pilot testing.

Pilot results demonstrated excellent performance of both the GAC-based and RO-based treatment processes. Extensive

> The SWIFT program will enhance the sustainability of the region's long-term groundwater supply and reduce the existing permitted nutrient load currently entering the sensitive Chesapeake Bay.

Table 1

Treatment option	Capital	Annual O&M	Net present value
RO	$170 million	$7.2 million	$281 million
NF	$157 million	$6.4 million	$256 million
GAC	$128 million	$3.5 million	$182 million

Cost comparison between different advanced water treatment trains for a generic 75.7 million liter per day- (mld) plant.

Table 2

GAC-Based Train			RO-Based Train		
Criteria	Value	Unit	Criteria	Value	Unit
Feed Flow	0.28	L/s	Feed Flow	1.8	L/s
ACH Dose	25	mg/L	NH2Cl Dose	3	mg/L
Plate Loading Rate	6	m3/d/m2	MF Flux	47.5	LMH
NH2Cl Dose	3	mg/L	RO Array	2:1	
Ozone Virus Log Removal Target	3	LRV	RO Design Recovery	83	%
Biofilter Empty Bed Contact Time[1]	10	min	RO Design Flux	20.4	LMH
GAC Column Empty Bed Contact Time	20	min	H2O2 Dose	5	mg/L
UVD target MS2 Removal	6	LRV	UVAOP target 1,4-Dioxane Removal	0.5	LRV

[1]GAC media was used in the biofilter and was exhausted of adsorptive capacity prior to pilot operation.

Pilot testing design criteria

Table 3

Location	LRV
GAC-BASED TRAIN	
Floc/Sed	1
Ozone	2
BAF	3.5
GAC	>1
UVD	N/A
Cl2	N/A
RO-BASED TRAIN	
UF	3
RO	>5
UVAOP	N/A

Pilot removal MS2 during challenge test

Table 4

Parameter	Monochloramine			Free Chlorine		
	30 min	2 hours	8 hours	30 min	2 hours	8 hours
Free Chlorine/ Monochloramine residual (mg/L)	1.0	1.0	0.8	1.7	.4	0.8
TOC (mg/L)	3.3	3.3	3.3	3.2	3.1	3.2
TTHM (ug/L)	0.0	0.0	0.0	17.2	28.3	58.6
NDMA (ng/L)	0.0	0.0	0.0	0.0	0.0	2.6
HAA5 (ug/L)	0.0	1.0	1.2	5.9	7.3	15.0

DBP formation in GAC-based pilot train

sampling was conducted daily, weekly, and monthly for a suite of parameters that included Safe Drinking Water Act (SDWA) parameters, a wide variety of trace organics, and additional contaminants not yet regulated by drinking water standards. Twenty different sampling events for all SDWA parameters were conducted for the GAC-based train, and seven sampling events were conducted for the RO-based train. During all sampling, only one parameter, acrylamide, was measured at a level higher than 50 percent of the maximum contaminant level (MCL). This finding occurred in the effluent of the GAC-based train and is thought to be because there is acrylamide in the polymer used at the York facility.

Pathogen removal

Both the GAC-based and RO-based treatment trains were designed with multiple barriers to pathogens. While HRSD was regularly sampling for pathogens, it was difficult to quantify *Cryptosporidium* and *Giardia* removal because protozoa were rarely detected in the pilot influent (secondary effluent). Of the viruses measured, the non-pathogenic pepper mild mottle virus was detected with the most frequency and highest levels in the pilot influent.

Figure 1 shows the removal of pepper mild mottle virus during multiple sampling events. In order to better quantify pathogen removal, a challenge test was performed using the bacteriophage MS2 as a pathogen surrogate. Concentrations above 10^8 Plaque Forming Units (PFU) per 100 million liters (mL) were measured in the pilot influent during the challenge test. Table 3 shows the measured log removal values in each treatment process for both pilot trains. In both trains, the MS2 was below the level of quantification before the disinfection steps, so it was assumed that there is much more than 8-log virus removal in both trains.

Organics removal

One of the primary goals of pilot testing was to evaluate the organics removal in the GAC-based train as the media became exhausted. The main criteria used to evaluate performance were total organic carbon (TOC) and trace organics. As expected, the TOC in the RO-based train was consistently below 0.2 milligrams per liter (mg/L). Figure 2 shows the total TOC through the GAC-based train over the duration of pilot testing. Figure 3 shows how the removal of TOC varies with increasing GAC bed volumes. The following notable observations can be made while evaluating Figures 2 and 3:

- Pilot influent TOC ranged from 6-9 mg/L (avg = 7.5 mg/L), while the effluent TOC stabilized around 3-3.5 mg/L after the adsorptive capacity of the GAC was exhausted
- Although temperature is not shown on Figure 2, the BAF TOC removal is shown to decrease in the winter months and increase in the warmer months
- GAC removal of TOC stabilized between 20-30 percent after approximately 20,000-30,000 bed volumes.

Monthly sampling for trace organics, including a suite of 90 pharmaceuticals, hormones, herbicides, and personal care products, was conducted during the pilot testing periods. The total number of detected trace organics throughout both the GAC-based (through October 2017) and RO-based (through December 2016) treatment processes are shown in Figure 4. The constituents that were most regularly identified in the GAC-based effluent were Acesulfame-K, iohexol, sucralose, and 4-nonylphenol (detected in 71 percent, 65 percent, 59 percent, and 18 percent of samples, respectively). The constituents most regularly detected in the RO-based effluent were sucralose, 4-nonylphenol, and 4-tert-octylphenol (detected in 44 percent, 33 percent, and 22 percent of samples, respectively).

Disinfection byproduct (DBP) testing was performed on both the GAC-based and RO-based train by adding free chlorine and monochloramine to the treated water and measuring total trihalomethane (TTHM) and haloacetic acid (HAA) formation after specific time intervals. A chlorine residual (either free or monochloramine) of 0.5 mg/L after 8 hours was targeted during the testing. The RO-based train showed minimal formation of DBPs and is not shown. Table 4 provides the DBP formation of the GAC effluent with both monochloramine and free chlorine addition. Although only 5 minutes of residence time is expected for SWIFT applications prior to introducing SWIFT water to the groundwater, DBP formation occurred at intervals of 30 minutes, 2 hours, and 8 hours. TTHM and HAA formation was significantly reduced with monochloramine compared to free chlorine.

Figure 1. Pepper Mild Mottle Virus Removal in Pilot

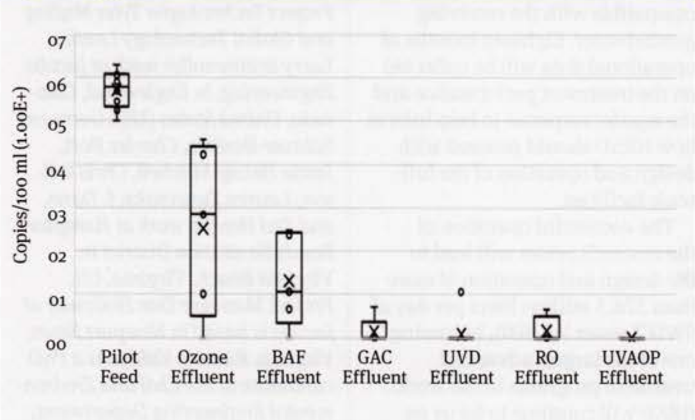


Figure 2. TOC for GAC-Based Train

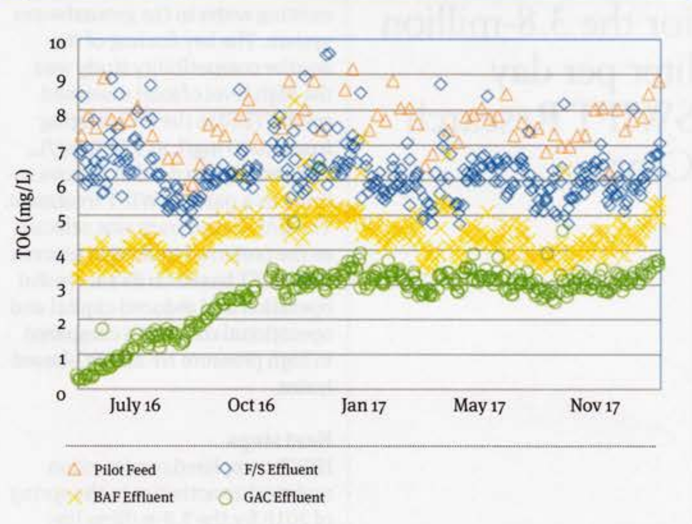


Figure 3. TOC removal in GAC vs Bed Volumes

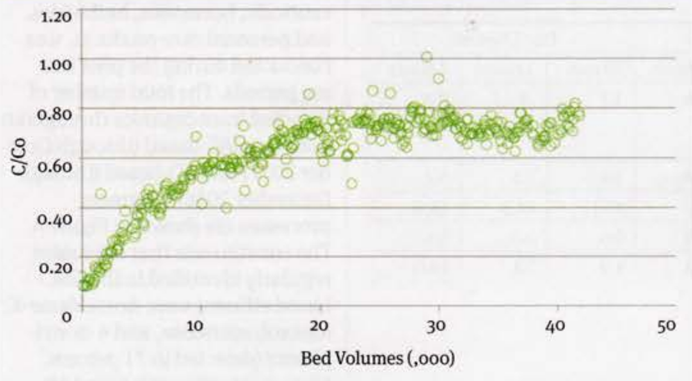


Figure 4. Mass and number of trace organics detected in pilot testing

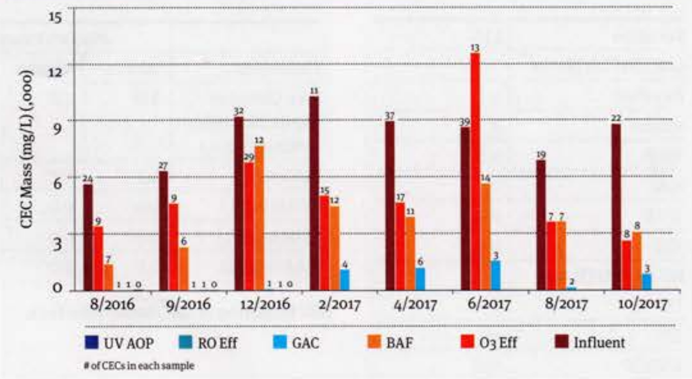
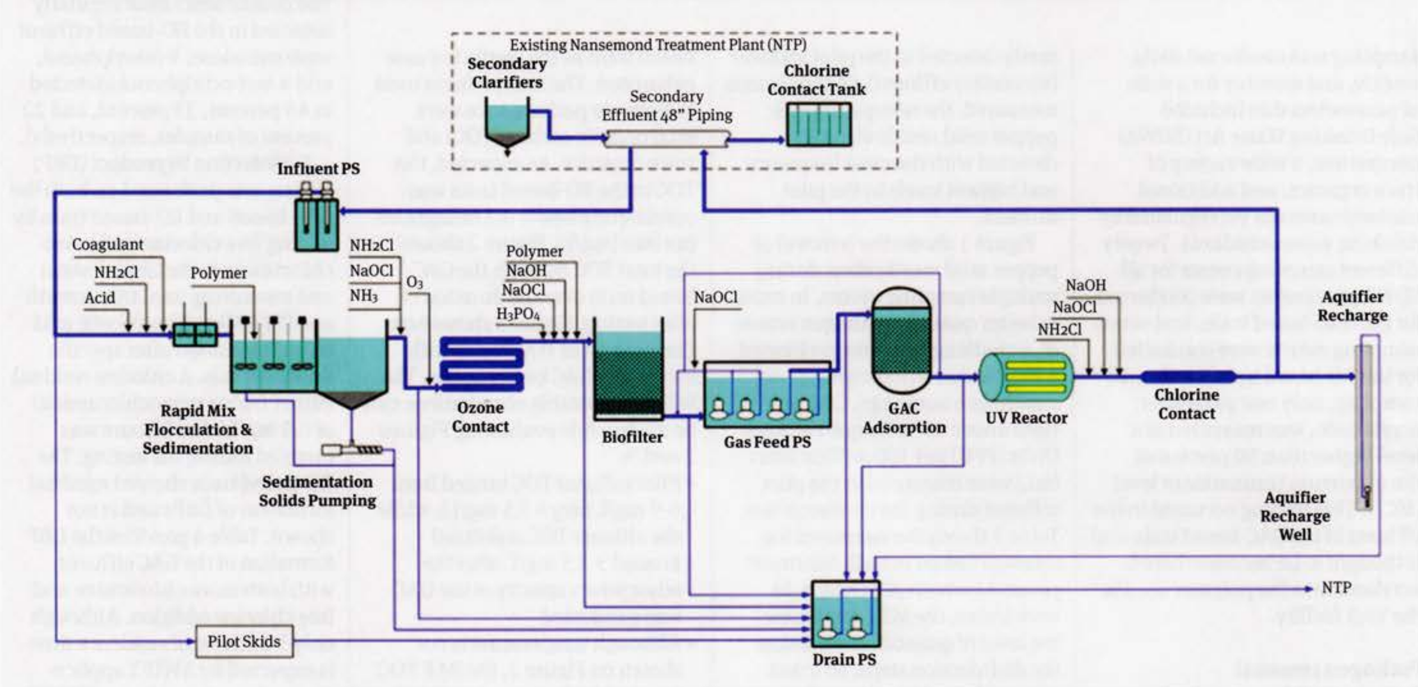


Figure 5. Swift Research Centre Process Flow Diagram



HRSD completed construction and startup activities in the spring of 2018 for the 3.8-million liter per day SWIFT Research Center.

Overall, the pilot test results confirmed that both treatment processes could produce potable water that meets all drinking water requirements and is protective of public health. While pilot testing was occurring, extensive sampling and modeling was performed to characterize the quality of the existing water in the groundwater system. The key finding of the aquifer compatibility study was the high level of total dissolved solids (TDS) in the PAS ranging from 1,000 mg/L to 5,000 mg/L, eliminating the need to remove salinity as a part of SWIFT treatment. The GAC-based train was selected as the preferred treatment process for SWIFT based on its successful operation and reduced capital and operational cost when compared to high pressure NF and RO-based trains.

Next steps

HRSD completed construction and startup activities in the spring of 2018 for the 3.8-million liter per day SWIFT Research Center, located at HRSD's Nansemond Treatment Plant. The purpose of the research center is to demonstrate at a meaningful scale that the GAC-based treatment process can effectively produce SWIFT water that meets the established regulatory requirements and is compatible with the receiving groundwater. Eighteen months of operational data will be collected on the treatment performance and the aquifer response to help inform how HRSD should proceed with design and operation of the full-scale facilities.

The successful operation of the research center will lead to the design and operation of more than 378.5 million liters per day of SWIFT water by 2030, becoming one of the largest advanced treatment programs in the world. HRSD will continue to focus on research objectives to optimize the advanced treatment and quantify the level of treatment that occurs after recharge. The performance of the SWIFT Research Center will be used to work with the regulatory agencies and program stakeholders to develop appropriate treatment requirements for the full-scale facilities.

Authors' Note

Project Technologist Tyler Nading and Global Technology Leader Larry Schimmoller work at Jacobs Engineering, in Englewood, Colorado, United States (US). Germano Salazar-Benites, Charles Bott, Jamie Heisig-Mitchell, Chris Wilson, Lauren Zuravnsky, J. Dano, and Ted Henifin work at Hampton Roads Sanitation District in Virginia Beach, Virginia, US. Project Manager Dan Holloway at Jacobs is based in Newport News, Virginia. Ramola Vaidya is a PhD candidate at the Civil and Environmental Engineering Department, Virginia Tech, in Blacksburg, Virginia. For more information, contact the author by email at Tyler.Nading@jacobs.com.