Anne Arundel County OurwAAter Program Managed Aquifer Recharge Pilot Project

Independent Advisory Panel Findings and Recommendations for Meeting on September 21, 2023

Prepared for
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Introduction

The National Water Research Institute is pleased to present the findings and recommendations from a meeting of the Independent Advisory Panel to review Anne Arundel County's (AACO) proposed managed aquifer recharge (MAR) project (Project). The Project is an early-phase investigative element of AACO's OurwAAter Program. OurwAAter is intended to provide long-term benefits by protecting the Chesapeake Bay while also improving groundwater quality and local water supply resiliency. NWRI convened and facilitated the meeting on September 21, 2023.

Background

Anne Arundel County engaged NWRI to organize an Independent Advisory Panel to review the proposed MAR Project under Agreement No. 10797 and Purchase Order No. 182952-000-OO. AACO contracted with NWRI to administer and facilitate this Panel to help guide the County's planning, sampling, pilot testing, and implementation processes.

The Panel review process for the Project is designed to provide feedback and recommendations on scientific, technical, regulatory, and outreach elements of AACO's proposed MAR Project. Members of the Panel include:

- Thomas Missimer, PhD, Florida Gulf Coast University, Panel Chair
- Diana Aga, PhD, University of Buffalo
- Charles Bott, PhD, Hampton Roads Sanitation District
- Scott Fendorf, PhD, Stanford University
- Mehul Patel, PE, Orange County Water District
- Steve Via, MS, American Water Works Association

A brief biography of each Panel member is on the NWRI website at www.nwri-usa.org.

Note that the technical experts on the Panel are available to consult through the Panel Meeting process and by communication through the NWRI Project Manager. Direct communication between Panel members and the Project Team should be limited to these channels.

Project Overview

Because the quality of life in Anne Arundel County is closely connected to groundwater supplies and water quality in the Chesapeake Bay, AACO has adopted a One Water approach to protecting and enhancing water resources within its control. This approach, known as the OurwAAter program, has two primary objectives: 1. Enhancing the resiliency of the region's groundwater supply, and 2. Reducing nutrients discharged to Chesapeake Bay.

The County has evaluated several alternatives to achieve their objectives and has identified aquifer enhancement by managed aquifer recharge as a cost-effective alternative. Tertiary effluent from the Patuxent Water Reclamation Facility will be treated using a multi-barrier advanced water treatment (AWT) process configuration consisting of five main steps including coagulation/flocculation and sedimentation, ozonation, biofiltration, granular activated carbon adsorption, and ultraviolet (UV) disinfection. While each step will contribute to greater overall pathogen and organics removal, these AWT processes will also provide treatment for emerging contaminants and will produce finished water that meets drinking water standards. The finished water from the AWT system will be used for groundwater augmentation by injecting the recycled water back into the groundwater aquifers.

Research investigations for the project consist of an aquifer evaluation that will inject treated wastewater into the aquifer system combined with analytical testing and monitoring. The first step evaluates the treatment process before actual testing in the aquifer begins.

The local and regional groundwater resource issues and the nutrient balance of Chesapeake Bay need to be addressed collaboratively by Anne Arundel County and the State of Maryland regulators. The AACO MAR Project has the potential to help lessen the impacts on regional groundwater resources and water quality. Fully understanding the Project's potential consists of verifying the science-based Project design by collecting field data and then modeling groundwater flow and solute transport. Collaboration will be important to integrating the Project into regional US Geological Survey and Maryland Geological Survey groundwater models.

Purpose of Meeting

The objectives of the September 21, 2023, meeting were:

- Tour the Pilot Project and update the Panel on the operations and data results.
- Present the advanced water treatment pilot results to-date and discuss next steps.
- Allow time for the Panel to begin drafting their recommendation report.

Review Materials

Before the meeting, AACO provided the following materials to the Panel for review:

- AACO Project Team responses to comments from Maryland Department of the Environment (MDE) on the AACO Mid-Term AWT Pilot Memorandum
- AWT bench-scale test results from HDR, the Project Team technical consultants

The Panel toured the Pilot Project facility on the day of the meeting, which greatly informed their understanding of the work that AACO is doing. The panel members were impressed by the pilot project and asked many questions about operations and the test apparatus. The interaction between the Panel and the Project Team began at the site and continued in the afternoon meeting.

Organization of the Report

The following section presents the NWRI Expert Panel's consensus Findings and Recommendations. In the next section, the AACO Project Team responds to comments from MDE in a memo titled "Responses to MDE Comments on Mid-Term AWT Pilot Memorandum," dated September 9, 2023. The Panel added more comments and recommendations after the AACO Project Team responses.

Appendices provide supplemental information, including Appendix A, About NWRI Panels; Appendix B, the meeting agenda; and Appendix C, a list of meeting attendees.

Panel Findings and Recommendations

The Panel's consensus findings and recommendations presented here are derived from a review of the materials provided to the Panel, the presentations by the AACO MAR Project Team, and interactive Panel discussions during and after the meeting.

The Panel recognizes the significant efforts by the Project Team and commends the Project Team for the progress made to date. The overall Project Pilot Test (Pilot) is designed and implemented using a high degree of quality engineering and good science. The Panel visited the Pilot test facility and appreciated the opportunity to ask questions and discuss each unit process in the advanced treatment system with the Pilot Operators.

Operation of the Pilot has proven successful. However, the purpose of Pilot projects is to detect operational issues that the Project Team must address when designing advanced water treatment unit process systems and control for an effective full-scale treatment facility. The Panel also understands that several of the operating issues that have occurred are related to the scale of the pilot system and would not occur during the operation of a full-scale plant.

The following subsections address topics that came up during the presentations and Q&A; the Panel also provides some general observations and recommendations that are not specific to Project Team questions or presentations.

DBP Formation

Fluorescence excitation-emission matrix spectroscopy (FEEM) has been used as a gross estimate of natural organic matter, which serves as a surrogate for disinfection byproduct (DBP) formation potential.[1] Quantifying and identifying actual DBPs using other analytical methods such as mass spectrometry is more difficult. Orange County Water District has used FEEM to monitor changes in organic matter in feed water to its membrane systems along with liquid chromatography/mass spectrometry analysis, using a lab at the University of Waterloo in Canada.

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[1] Fernandez-Pascual, E., Droz, B., O'Dwyer, J., O'Driscoll, C., Goslan, E. H., Harrison, S., & Weatherill, J. (2023) Fluorescent Dissolved Organic Matter Components as Surrogates for Disinfection Byproduct Formation in Drinking Water: A Critical Review. *ACS EST Water*, June 12, 2023; 3(8): 1997-2008. https://doi.org/10.1021/acsestwater.2c00583

The Panel suggests that testing samples from the injection well for total organic halogens (TOX) might be a tool the team could use to understand DBP formation potential in the groundwater. In addition, testing samples from the wellhead and from monitoring wells may show that DBPs and DBP formation potential are not an issue farther from wells. Such test results may help to address concerns expressed by MDE.

Turbidity

The Panel believes that the size and piping configuration of the pilot treatment system is likely the cause of ongoing turbidity issues. The issue should be resolved at a demonstration scale facility since chemical dosing and flow hydraulics will be better optimized.

The use of ferric chloride in the pilot facility was effective in coagulating organic matter and producing flocs with acceptable hydraulic properties to encourage settling. However, downstream turbidity was adversely affected by this substance, which required the Project Team to use a less effective chemical for coagulation.

The Panel suggests that the Project Team consider using ferrate as an alternative coagulant. The dose rate for ferrate would be about 10 percent of the ferric chloride dose. Ferrate tends to bind a higher percentage of small organic compounds and produces a floc size that allows more effective settling. It also acts as a disinfectant.[2]

PFAS

Method 1633

The Panel understands that the Environmental Protection Agency (EPA) recommends Method 1633 but feels that the data from other methods will be more reliable and useful for the Project Team.

Method 1633 measures 40 targeted per- and polyfluoroalkyl substances (PFAS) in wastewater, surface water, groundwater, and leachate. The target analytes range from 4-carbon chain PFBS

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[2] Alshahri, A. H., Obaid, M., Abdullah, H. A. D., Missimer, T. M., Ali, M., Ghaffour, N. (2023). Combination of advanced coagulation Fe(VI) and UF membrane to effectively remove organic compounds and mitigate potential biofouling during harmful algal blooms. *Desalination* 565, 116882. November 2023. https://doi.org/10.1016/j.desal.2023.116882

and PFBA to 14-carbon chain PFTeDA. However, short-chain PFBS and PFBA have very low recoveries that are highly variable, as well as high detection limits.

The EPA notes in draft Method 1633 that these compounds are "…poor performers and that data users and laboratories should take that information into account." Because of the relatively lower sorption of shorter-chain PFAS, these forms are more important to monitor in drinking water. Therefore, it is important to have replicate analysis of samples to increase confidence in the measured concentrations of short-chain PFAS.

The Panel believes that it is important to have replicate samples analyzed to obtain more reliable data for short-chain PFAS. The Panel understands that having replicate samples sent to an accredited laboratory can be cost prohibitive and recommends sending some samples to a university laboratory to double-check for the presence of short-chain PFAS, as well as other potential PFAS byproducts, using nontargeted analysis.

There are many analytes listed in Method 1633 that are not expected to occur in water that has been treated using activated carbon (AC) because the long-chain PFAS will be effectively sorbed on AC. Therefore, it is more important to send samples for analysis at a lab that can measure short-chain PFAS and show reproducibility by analyzing replicate samples than it is to have samples tested using Method 1633.

Sources of PFAS

The Panel understands that landfill leachate, which is a recognized source of PFAS, is discharged into the wastewater collection system and enters the treatment facility. The Panel recommends that the Project Team consider separating this discharge and developing a treatment system for landfill leachate. The Panel also notes that soon-to-be regulated PFAS are already quite low in the treated wastewater that flows into the advanced treatment plant, so this may not be an issue.

Dissolved Oxygen

The issue of dissolved oxygen (DO) in injected recharge water has been raised several times. High concentrations of DO have been known to mobilize metals, such as chromium and uranium, in aquifer storage and recovery (ASR) systems. Oxidation alone, however, is not sufficient for mobilization.

For uranium, oxidation needs to be followed by conditions that lead to the formation of uranyl-calcium-carbonato complexes that occur at moderately high pH, bicarbonate, and calcium-bearing waters.[3] For chromium, DO needs to be accompanied by pH values typically greater than nine for trivalent chromium (Cr[III]) to react at meaningful rates.[4]

However, high DO can immobilize arsenic in some specific locations/circumstances. The Panel notes that this recharge project is not an ASR system. DO concentration in the water injected into the aquifer will decrease as the water moves away from the injection well. DO is reduced by biochemical oxygen demand and chemical oxygen demand of the water and reductants, such as hydrogen sulfide, in the aquifer.

The Panel strongly recommends that the Project Team investigate how DO decreases during the aquifer testing phase of the investigation.

Additional Panel Feedback

Confirm Pilot Components and Processes. The Panel recommends that the Project Team double-check and verify all components of the pilot test skid, including chemistry, and all processes in the treatment train. It is important to independently verify performance to ensure that data generated by the pilot test program is accurate. Validate all chemical feeds, set points, flow meters, empty bed contact time and filter loading calculations, G and GT (G=velocity gradient, T=detention time) values for rapid mixing and flocculation, and any other components and processes.

The Purpose of Pilot Testing. Pilot programs should find problems and allow project teams to identify solutions for demonstration- or full-scale systems. Pilot programs are a process for testing concepts and troubleshooting design issues; therefore, it is important that the pilot is evaluated based on the final product water quality coming out of the system, and not on each individual step or barrier in the process. Operational problems at the small pilot scale that is being used by AACO are expected for such testing. The information gained from the pilot will

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[3] Lopez, A.M., Wells, A., & Fendorf, S. (2021). Soil and Aquifer Properties Combine as Predictors of Groundwater Uranium Concentrations within the Central Valley, California. *Environ. Sci. Technol.* 2021, 55, 1, 352-361. https://doi.org/10.1021/acs.est.0c05591

[4] Eary, L. E., & Rai, D. (1987) Kinetics of chromium(III) oxidation to chromium(VI) by reaction with manganese dioxide. *Environ. Sci. Technol.* 1987, 21, 12, 1187-1193. https://doi.org/10.1021/es00165a005

allow the Project Team to further optimize processes at demonstration scale. The product water quality shown to date from the pilot project indicates that the treatment train being tested can be successful at demonstration scale.

Collaboration between Stakeholders. The Panel continues to encourage collaboration and frequent communication between the AACO Project Team and the MDE, which holds regulatory authority for this project. Stakeholder collaboration supports the goals of the OurwAAter program, which are to enhance the resiliency of the region's groundwater supply and reduce nutrients discharged to Chesapeake Bay. Outreach to all affected stakeholders is key to a successful project. The outreach program from AACO should strive to reach all affected parties.

Questions from Maryland Department of the Environment

MDE Comment

1. Page 2, Table 1 of the Mid-term AWT Pilot Memorandum. The treatment objective of TOC <4 mg/l (monthly average) may not be adequate in protecting groundwater quality and public health. A groundwater TOC study conducted in 8 European Union countries with mostly unconsolidated sand/sandstone aquifers indicated the mean and median TOC concentrations were around 2 mg C/L for 439 samples [1]. Florida requires TOC <3 mg/l for Groundwater Recharge to a Potable Aquifer via Injection [2]. The California Article 5.2 - IPR Regs for Indirect Potable Reuse: Groundwater Replenishment – Subsurface Application requires TOC <0.5 mg/l (§60320.218. Total Organic Carbon Requirements) [3]. The average TOC concentration of 1 mg/l for the GAC effluent shown in Figure 8 of this Mid-term AWT Pilot Memo exceeds the California TOC limit of 0.5 mg/l.

   Public water supply wells downgradient from the Patuxent WRF groundwater injection well such as Charles County Utilities' wells serving Waldorf and Bryans Road areas use groundwater from Patapsco and Patuxent aquifers as source of drinking water and use chlorination as a disinfection process. Higher TOC in source water may result in higher DBPs in treated water and cause violations of Drinking Water Standards. Water quality impact to private wells downgradient of the injection well is also of concern.

   Higher TOC concentration in groundwater enhances the microorganism growth including pathogens and ion bacteria which may increase the well screen or aquifer media clogging potential.

   It is recommended the TOC treatment objective of this pilot study be revised to meet the lowest number of either the background TOC concentration of the aquifer receiving treated wastewater, or the California limit of 0.5 mg/l. An aquifer groundwater sample collection and TOC analysis are necessary for determining the background groundwater TOC concentration.

Project Team Response[5]

Generally, it should be noted that average groundwater TOC levels can vary significantly by location. We support investigating the groundwater TOC levels near the proposed injection sites to ensure groundwater compatibility.

California's TOC limit is based on the performance of a required advanced water treatment process – reverse osmosis (RO), meaning the TOC limit is based on a treatment standard rather than a finished water standard. It should be noted that Cal. Code Regs. tit. 22 § 60320.130 allows for increased finished water TOC concentrations if approved through the process described in the regulation.

It is assumed that Florida's TOC limit is based on disinfection byproduct and contaminant reduction, however according to the EPA, the technical basis for the TOC limit is not explicitly specified (US EPA, 2021). The Anne Arundel County AWT pilot TOC treatment goal of 4 mg/L is based on HRSD SWIFT's finished water TOC goal, which was drawn from the results published in several indirect and direct potable reuse studies.

These studies found that TOC concentrations as high as 4 mg/L were commonly found in drinking water plants and represented a minimal public health risk as long as sufficient monitoring of surrogates was included (Funk et al., 2018; Schimmoller et al., 2020). These surrogates include CEC indicators like iohexol and sucralose and disinfection byproducts (DBPs).

The pilot study is investigating formation of DBPs through surrogate studies, such as DBP formation potential assays where varying doses of disinfectants are tested. One point of consideration is that DBP formation potential (DBP-FP) correlates to the concentration of "reactive" TOC precursors, not bulk TOC.

The TOC present in the AWT finished water has been treated by multiple chemical and biological oxidation processes, including chlorination. These processes are expected to decrease aromaticity, and other DBP precursor characteristics, significantly reducing

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[5] *Note: Please note that Independent Advisory Panel Findings and Recommendations for Meetings 1 and 2, April 27 and May 26, 2022, provide additional discussion of this general question.*

subsequent reactivity with chlorine during groundwater injection. The reactivity (DBP-FP) of pilot AWT finished water will be characterized during the study.

Appendix B, Table 14 includes the finished water quality concentrations and none of the DBPs have exceeded the drinking water MCLs. Chlorinated DBPs such as trihalomethanes and haloacetic acid concentrations are below detection in the finished water. DBP formation potential with chlorine will be tested on the finished water to ensure no more DBPs are formed after injecting in the aquifer.

Note that the current plan at the Patuxent WRF is to only inject finished AWT water into deeper aquifers (Lower Patapsco and Patuxent) that have limited private drinking water wells. If the facility proceeds to full-scale, the County could consider connecting these private wells to the public drinking water supply. Future DPW drinking water supply from these aquifers will need to comply with all drinking water regulations.

Panel Comments

The Panel recommends that Anne Arundel County obtain background total organic carbon (TOC) values in the aquifers to determine the need for TOC removal from treated wastewater before it is injected. Background testing of water in the aquifer allows a proper assessment and comparison of the injectate water chemistry and the aquifer water chemistry to help determine geochemical compatibility. The TOC in the injected water does not necessarily need to be equal to or less than that found in the formation, but it needs to be geochemically compatible. The Panel also suggests that the TOC in both the treated wastewater and the aquifer be characterized to determine the bioactive portion of the TOC and what part is recalcitrant and non-reactive for DBP formation potential. Based on that further characterization, the TOC concentration issue should be revisited using real data.

The Panel suggests that the Project Team acknowledge the benefit of soil aquifer treatment for TOC and other contaminant removal. The benefits of soil aquifer treatment can be evaluated during the demonstration phase of the project by analytical testing on samples collected from properly spaced monitoring wells.

MDE Comment

2. Page 2, Table 1. It is recommended to add a treatment goal of DO (dissolved oxygen). The DO treatment goal is to meet the lowest number of either the background DO concentration of the aquifer receiving treated wastewater, or less than 2 mg/l for the following reasons: (1) To minimize the Oxidation-Reduction Potential (ORP) in the recharged aquifer. Higher ORP will enhance the formation of ferric oxide (see an example shown in Attachment 1 and 2 for pH = 8.25 and DO = 10 mg/l). The ferric oxide solids enhance the aquifer media and well screen clogging potential [4], (2) To minimize the oxidation of pyrite and arsenic release., and (3) The median background DO concentration in a confined aquifer is likely less than 2 mg/l.[5]

   An aquifer groundwater sample collection and DO analysis are necessary for determining the background groundwater DO concentration.

Project Team Response

- Elevated DO will tend to oxidize dissolved iron in the finished water. However, the average dissolved iron concentration in the finished water is near 0 µg/L which is insufficient to cause plugging in the well screen or filter pack. Since precipitation of dissolved iron in the native groundwater occurs only one time in the mixing zone for MAR applications, we do not believe elevated DO is a significant risk related to formation plugging (National Water Research Institute, 2023). If plugging was observed during testing, the project team would need to develop operational and control strategies to mitigate the impact while maximizing production. In concept this is similar to the development of backwash sequences for filtration systems or cleaning schedules for membrane systems.

- DO between 8 and 14 mg/L will likely cause oxidation of iron bearing minerals, such as pyrite, if present. This process could release associated arsenic if present. However, if the average pH and alkalinity are maintained between 8.0 and 8.5 , and 80 – 140 mg/L, respectively, the high DO should cause the dissolved iron to quickly precipitate as hydrous ferric oxide (HFO). HFO tends to adsorb arsenic and other dissolved metals. At the proposed pH and alkalinity concentrations, HFO should be stable. Within a short distance of the recharge well, the DO should be consumed and approach the concentration of the native groundwater. The recharged water should no longer be reactive with iron minerals, if present. The converse effect described herein was observed at the HRSD SWIFT facility, where a period of operation resulted in low DO finished water that caused an arsenic release that was mitigated by increasing the DO concentration (HRSD SWIFT, 2022).

- We understand that there continues to be disagreement on the reactivity and impacts if DO in the aquifer. We think the best way to resolve this issue is through development of an aquifer injection testing plan that will not have any lasting impact to the aquifer system.

Panel Comments

The two big concerns for arsenic mobilization are pH values higher than 8.5 or low DO conditions that can lead to the reductive dissolution of As(V) adsorbed on sediment minerals such as ferric (hydr)oxides.

While the dissolved iron concentration is quite low in the treated wastewater that will be injected, concentrations in the receiving aquifer need to be measured during the test program to determine if it is necessary to adjust DO in the injected water. Adjusting DO concentration is used in ASR systems to reduce the potential for arsenic and molybdenum mobilization.

However, water recovery or reuse is not a component of the project design. Once the injectate enters the storage aquifer, the DO concentration will decline as water moves away from the injection well, in part through the oxidation of ferrous to ferric iron and the generation of ferric (hydr)oxides. Dissolved metals and arsenic will adsorb on the ferric (hydr)oxides.

Metals that are prone to be retained on minerals under anoxic conditions will sorb on the aquifer strata beyond the oxygenated injection zone. Since the aquifer is anoxic, DO should be depleted shortly after the water is injected. How rapidly DO declines should be measured in the field during the injection test phase.

It is correct that DO oxidizes pyrite, which may release arsenic if the pyrite is arsenic bearing. However, not all aquifers contain pyrite or other arsenic-bearing sulfide minerals, and ferric (hydr)oxides that are generated in the oxidation process are superb arsenic scavengers. Thus, arsenic is simply transferred from one solid phase to another.

The Project Team referenced appropriate pH and alkalinity (ALK) ranges to ensure HFO precipitation. While the ALK range is reasonable, the pH range is higher than necessary in most cases. Geochemical modeling should be performed based on aquifer oxidation-reduction potential (ORP) as recharge proceeds. Where the ORP in the aquifer near the well is quite high, a pH as low as about 6.5 to 7.0 may be admissible depending on the ALK.

MDE Comment

3. Page 2, Table 1 and Page 16, Table 8. The pathogen reduction objective/credit in meeting 10 LRV (log10 reduction value) for cryptosporidium may not be achievable. The LRV of 9.05 shown on Table 3 of Attachment 3 for cryptosporidium was estimated based on LRV included in the 2017 Potable Reuse Compendium.[2] Table 10 of the Mid-term pilot Memo indicates the maximum observed log reduction for cryptosporidium through Pilot operation was determined as "unable to determine".

   It is recommended to increase the design UV dose from 100-180 mJ/cm2 shown on Table 4 of the Mid-term AWT pilot Memo to 800 mJ/cm2 to proportionally increase the LRV from 3.4 to 6 for cryptosporidium shown on Table 3 of Attachment 3. This will accomplish the cryptosporidium 10 LRV goal expected for all proposed AWT treatment processes.

Project Team Response

Table 4-3 of Attachment 3 mentioned by the reviewer displays the minimum *Cryptosporidium* log-reduction observed at a fluence of 800 mJ/cm^2 based on pathogen densities in raw wastewater. As stated in the EPA's 2017 Potable Reuse Compendium, "Log reduction credits are a function of the detection limit of the analytical technique and the concentration present or injected in the feed water to the unit process." The values in Attachment 3 are likely determined by the concentration of *Cryptosporidium* present in raw wastewater, as indicated by the "minimum value" reporting.

For tertiary effluent (influent to the AWT pilot), *Cryptosporidium* was not detected, therefore log removal estimates for a given disinfectant dose are theoretically estimated. In conventional secondary wastewater treatment, log removals of *Cryptosporidium* have been estimated to range from 0.7 to 1.5 log10 reductions (US EPA, 2017), however our study does not assume any pathogen credit through wastewater treatment.

The table below presents the dose response of *Cryptosporidium* in Table 1.4 of the UV Disinfection Guidance Manual for the EPA's Final Long Term 2 Enhanced Surface Water Treatment Rule. At a fluence of 22 mJ/cm^2, a 4-log reduction of *Cryptosporidium* is achieved.

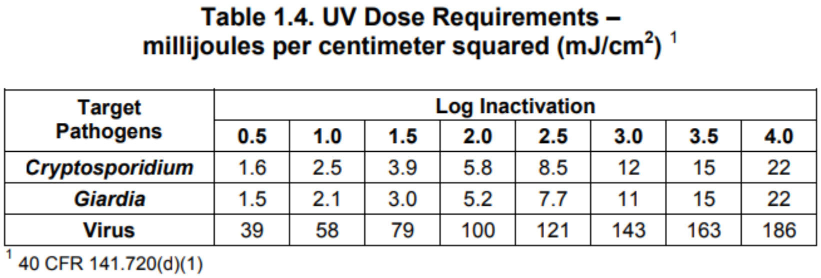

Table 1.4. UV Dose Requirements – millijoules per centimeter squared (mJ/cm^2) [1]

Target Pathogens	Log Inactivation							
	0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

[1] 40 CFR 141.720(d)(1)

The dose response of *Cryptosporidium* is well documented in papers including, "*Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae*" (Malayeri et al., 2016) and "*Susceptibility of five strains of Cryptosporidium parvum oocysts to UV light*" (Clancy et al., 2004). Clancy (2004) found, "a UV light dose of 10 mJ/cm^2 achieved at least 4-log10 inactivation of all [*Cryptosporidium*] strains evaluated."

Therefore, a fluence target of 186 mJ/cm^2 is expected to greatly exceed the 6-log reduction goal for *Cryptosporidium*. For additional information on subsequent pathogen benchmarking to be completed, please see section "Pathogen Removal Efforts" of the mid-term memorandum.

Panel Comments

The Project Team response is quite reasonable. Any UV reactor that is validated for 186 mJ/cm^2 and 4 logs of virus removal would be expected to provide more than 6 logs of *Cryptosporidium* inactivation.

It is important that ultraviolet transmittance (UVT) plays a significant role in pathogen reduction by UV. A large UV dose of 800 mJ/cm^2 for *Cryptosporidium* removal is only applicable to raw wastewater. Site-specific UVT based on upstream treatment by the pilot plant before the UV process is important.

MDE Comment

4. Page 24, Figure 13. It shows that pilot plant influent levels of PFAS can vary widely and that the GAC as operated is allowing some PFAS through. RO is highly effective in removing PFAS and TOC. RO should be included in the AWT design.

Project Team Response

The pilot team recognizes that variability in influent water quality is inherent and expected. This variability serves as a valuable tool to better comprehend the efficiency of the pilot system's performance. The pilot team will continue to monitor influent data to confirm and validate if there is an increasing trend in the PFAS levels to the pilot system or if this sampling point was an outlier with possible analytical variability.

Regarding GAC allowing certain PFAS to breakthrough, it is essential to understand that GAC operates through an adsorption process. Breakthrough of PFAS is a function of GAC media age; as the adsorptive sites decrease, there is the potential for more PFAS breakthrough.

Once adsorptive capacity is exhausted, contaminants can begin to breach the GAC system and reach the effluent water. At this point, the GAC media needs to be replaced; hence, it is critical to monitor GAC effluent and upstream ports in the GAC bed to determine when the breakthrough starts to happen. When a breakthrough is observed, the media is replaced to ensure the required water quality is met.

Fortunately, regular monitoring of upper and intermediate GAC bed sample ports can ensure that breakthrough of contaminants, especially those included in draft EPA PFAS regulations, do not fully breakthrough into the effluent. Indeed, this is why GAC is recognized as the best available technology for PFAS removal and cited by the EPA as the approach that will be most commonly implemented for national compliance with the Drinking Water PFAS Rule.

The goal of this pilot study is to estimate the GAC adsorptive capacity and GAC changeout frequency necessary to meet draft EPA regulations with the unique combination of wastewater composition and upstream treatment at this location. As depicted in Figures 12, 13, and 14 of the report, the pilot GAC system effectively removes the six PFAS outlined by the EPA's draft regulation, even after processing a cumulative volume of 10,000 GAC bed volumes (BVs). Breakthrough occurs for PFAS compounds not covered in the draft MCLs, such as PFBA and

PFPeA, beginning around 4,000 to 5,000 BV. PFHxA, which has a longer carbon chain length than PFBA and PFPeA, started to breakthrough at 7,000 BV.

In response to RO comparisons, EPA's draft proposal includes both GAC and RO (along with ion exchange and nanofiltration) as the best available technologies for PFAS removal that can provide > 99% of the PFAS included in the draft MCLs (US EPA, 2023). Drinking water utilities in Maryland are currently proceeding with implementation of GAC for treating high levels of PFAS in their drinking water.

As with any PFAS treatment method, competing anions can interfere with PFAS removal. No technology is infallible; therefore, treatment plants should monitor contaminants regularly at multiple locations in the treatment process to track the potential for breakthrough. Mastropietro et al. (2021) and Yadav et al. (2022) reported short-chain PFAS breakthrough up to 31% for PFBS in nanofiltration membranes and up to 7% for PFHxA in RO membranes, demonstrating that even membrane processes can experience contaminant issues.

EPA also lists additional considerations for both GAC and membrane technologies with respect to PFAS removal. For GAC, PFAS are absorbed and then thermally destroyed when the spent media is thermally reactivated to replenish adsorptive capacity. This effectively removes PFAS from the environment and prevents the waste stream from causing future contamination. The reactivation is performed by the GAC manufacturer and provides a renewable option for utilities seeking to reuse GAC.

On the other hand, while RO can produce excellent finished water quality, RO reject (concentrate) can contain high levels of PFAS, TOC, nutrients, and other contaminants that must be managed. PFAS are not destroyed in RO treatment systems but instead are separated out into a concentrated stream. As such, this concentrated stream should not be directly discharged to surface waters or sewersheds without additional treatment, such as GAC, or ion exchanged to prevent further contamination of waterways.

Additionally, RO flux recoveries can be as low as 60%, meaning the treatment process will lose up to 40% of the water treated while the rest is concentrated, requiring further treatment. Given the potential for significant water loss and concentrate treatment requirements, RO treatment was eliminated as a viable option for Anne Arundel County’s proposed MAR process.

To continue to validate GAC as a practical treatment method for MAR, the AWT pilot team is currently setting up rapid small-scale column tests (RSSCT) alongside the pilot to investigate various GAC media for PFAS removal. The findings from RSSCT will assist in identifying the most effective and cost-efficient media for PFAS removal.

Lastly, risk reduction continues to be a primary focus of the Anne Arundel County team. An important part of the piloting effort is to identify critical control points (CCPs) in an AWT process to reduce, prevent, or eliminate process failures. Results from the pilot study will inform selection of multiple CCPs in the AWT train that can be used in later phases to reduce risk.

Panel Comments

Granular activated carbon (GAC) systems can be designed and operated to remove regulated PFAS very effectively and in compliance with the proposed maximum contaminant levels (MCLs).

While RO effectively removes PFAS, some low molecular weight compounds can pass through membranes. The Panel does not think this low rate is applicable given the level of pretreatment expected by this project (or any considering RO). Minimal recovery of 75 percent is quite common in secondary or tertiary treatment with proper pretreatment. The overall response supports the idea that RO is not the best option for the AACO project. Furthermore, PFAS in the resulting RO concentrate stream would require treatment and disposal, which only relocates management of the PFAS issue.

The Panel notes that in paragraph eight of the Project Team Response, above, "absorbed" should be changed to "adsorbed."

MDE Comment

5. Page 28, Table 13. The Table titled "Geocompatibility Water Quality Boundaries" indicates that the lower desired concentration of dissolved oxygen is 8 mg/l and the upper level is 14 mg/l. Our original comments (Dec 2018) noted that the high oxygen concentrations (native deep groundwater has zero oxygen) in the effluent would cause many geochemical reactions. We questioned the advantage of injecting high oxygen water and potential downstream water quality issues, including the liberation of arsenic. In other words, water

with elevated oxygen was not compatible with aquifer water chemistry. The County's response to our initial comment was that the increased DO in an alkaline discharge would increase hydrous ferric oxide sites, therefore allowing for the removal of arsenic, iron and manganese in the migrating recharge water.

The quality of the treated wastewater to be injected into the aquifer should be geochemically comparable to the aquifer water quality especially pH and DO which affect the ORP.

ORP and pH are two important water chemistry parameters which determine the end products of the chemical reactions in the groundwater as shown in Attachments 1 and 2. Literature such as "Managed Aquifer Recharge" includes a section 2.5.2 – Geochemical Compatibility: Source Water -Aquifer Interaction to discuss various concerned issues. [6]. Comment No.2 recommends the DO in the effluent to meet a much lower DO concentration. It is recommended the pH of the effluent to meet 5.1 or lower. A pH average value of 5.1 was determined based on the measured pH values for Upper Patapsco, Lower Patapsco and Patuxent aquifers (see Figure B of Attachment 2)

Project Team Response

The proposed approach to managing arsenic levels in the MAR zones (by forming a stable HFO precipitate), has a substantially lower operating cost than reducing DO to less than 2 mg/L and pH to around 5.1 (See Question 2).

Therefore, this approach is recommended for injection well pilot testing, especially given the uncertainty regarding the existence of arsenic-baring minerals in the MAR zones. Other potential negative consequences of high DO in the finished water, such as increased corrosion potential of MAR-related infrastructure and accelerated biofouling of the formation, will also be assessed during injection well piloting and a quenching agent could be augmented if necessary.

Panel Comments

The Panel notes that the proposed method to achieve geocompatibility could be tested to demonstrate its effectiveness to MDE. The approach proposed by AACO is valid and is commonly used at similar projects across the country. The chemistry of the injectate water needs to be compatible with the water chemistry in the receiving aquifer, but individual analytes do not need to be equal to or less than concentrations that naturally occur in the aquifer.

MDE Comment

6. In reviewing the water treatment design, Maryland follows the Ten States Standards which require that the treatment is designed to meet half of MCLs. This requirement is applicable to the review of the Patuxent AWT design.

Project Team Response

The 2012 and 2018 Editions of the Ten States Standards were reviewed and no mention of treatment to half of drinking water MCLs was located. The Ten State Standards reference maximum contaminant levels (MCLs) several times, however they are only in reference to planning for technologies capabilities to remove arsenic, anion exchange capabilities for community water systems, and the process design for packed tower aeration, as shown below:

> Arsenic mention: “When planning facilities for arsenic reduction, it is recommended that the treatment be capable of reducing arsenic levels in the water to one-half the MCL (currently 5 ppb) or less.” Page xxii, 2018 Edition.
>
> Community system/IX mention: “For community water systems treating acute contaminants, at least two units shall be provided. The treatment capacity must be capable of producing the maximum day water demand at a level below the MCL for the contaminant of concern with one exchange unit out of service.” Page 79, 2018 Edition.
>
> Packed tower mention: “The tower shall be designed to reduce contaminants to below the maximum contaminant level (MCL) and to the lowest practical level.” Page 82, 2018 Edition.

MDE’s 2015 “Design Guidelines for Drinking Water Facilities” includes meeting the 10-State Standards as well as the Safe Drinking Water Act, applicable state laws and regulations, and issued/final EPA Public Drinking Water Rules and/or MDE guidance. The references included (EPA, AWWA, 10-State) also do not mention meeting half of MCLs for any constituent other than arsenic (10-State).

The AWT Pilot Team welcomes the opportunity to discuss recommended treatment goals and objectives with MDE. Per Table 1 of the Mid-Term Pilot Memo, the AWT pilot is designed to meet all SDWA standards as well as treat the water to greater standards than conventional drinking water treatment facilities. These treatment goals reference the EPA's Potable Reuse Compendium (US EPA, 2017) and the California State Water Resources Control Board's Recycled Water Policy (California Water Boards, 2023), which are the standard treatment references for potable reuse and do not include the requirement for half of the MCLs.

Parameter	Description	Treatment Objective
Safe Drinking Water Act Compliance	Group of diverse organic and inorganic constituents that are monitored and managed	• Reduce DBPs, organics, inorganics, radionuclides below MCLs[1] • Reduce below SMCLs[2] when appropriate • Reduce PFAS below draft MCLs[3]
Pathogen Reduction	Microorganisms that can be harmful to humans if consumed	• Meet most stringent 12-10-10 pathogen reduction treatment criteria set by the California State Water Board • Maintain disinfectant residual to reduce microbial risk
Finished Water Compatibility	TOC, turbidity, aquifer compatibility, corrosion control, microbial risk	• Maintain low effluent TOC (<4 mg/L) and turbidity (< 0.1 NTU for 95% of individual filter samples) • Work with MAR pilot staff to optimize finished water compatibility with aquifer • Maintain optimal WQ to reduce corrosion potential
CEC Removal	Pharmaceuticals, personal care products, endocrine disruptors, and industrial compounds	• Characterize CECs in source waters • Assess and optimize removal of CECs through treatment technologies and inform cost

[1] MCL is the abbreviation for Maximum Contaminant Level

[2] SMCL is the abbreviation for Secondary Maximum Contaminant Level

[3] PFAS draft MCLs: PFOA and PFOS, 4 ng/L and, Hazard index for the mixture of PFNA, PFBS, PFHxS, and GenX chemicals, 1.0.

Panel Comments

The Project Team states that the pilot is designed to meet all Safe Drinking Water Act standards. It is worthwhile to explicitly state that this includes both primary and secondary MCLs.

MDE Comment

7. It is suggested using EPA 1633 instead of EPA 537.1 to analyze the PFAS compounds from the effluent of the WWTP and AWT. EPA 1633 covers 40 compounds (compared to 18 covered by the 537.1). These additional compounds include precursors that may eventually be transformed into PFOA and PFOS in the aquifer. It is essential in determining the effectiveness of the AWT in removing all compounds.

Project Team Response

EPA Draft Method 1633 for aqueous matrices such as wastewater, surface water and groundwater is still being finalized and EPA recently released the fourth draft of this method. Compliance sampling for EPA's proposed PFAS MCLs are covered under EPA Methods 533 and 537.1.

Due to the draft nature of EPA Method 1633, the laboratory detection capabilities can vary significantly by lab. Additionally, EPA Method 1633 was designed to target PFAS in complex matrices (wastewater, soil, etc.) versus the EPA Methods 533 and 537.1 that target drinking water matrices.

Through discussions with the County's contract laboratory (Eurofins), the laboratory recommended using EPA Methods 533 and 537.1, due to the water quality of the pilot influent and effluent (low turbidity). The project team would prefer to maintain the current methods for consistency. However, if required, additional water samples using EPA Method 1633 can be collected at the end of the AWT process. The following table shows the analytes tested for each of these methods.

PFAS Compounds	EPA Method 533	EPA Method 537.1	Draft EPA Method 1633
Perfluorobutanoic acid	x		x
Perfluoropentanoic acid	x		x
Perfluorohexanoic acid	x	x	x
Perfluoroheptanoic acid	x	x	x
Perfluorooctanoic acid	x	x	x
Perfluorononanoic acid	x	x	x
Perfluorodecanoic acid	x	x	x
Perfluoroundecanoic acid	x	x	x

PFAS Compounds	EPA Method 533	EPA Method 537.1	Draft EPA Method 1633
Perfluorododecanoic acid	x	x	x
Perfluorotridecanoic acid		x	x
Perfluorotetradecanoic acid		x	x
Perfluoropropanesulfonic acid			x
Perfluorobutanesulfonic acid	x	x	x
Perfluoropentanesulfonic acid	x		x
Perfluorohexane sulfonate	x	x	x
Perfluoro heptanesulfonate	x		x
Perfluorooctane sulfonic acid	x	x	x
Perfluorononanesulfonic acid			x
Perfluorodecanesulfonic acid			x
Perfluorooctane sulfonamide			x
N-Methlyperfluorooctane sulfonamide			x
N-Ethlyperfluorooctane sulfonamide			x
N-Methlyperfluorooctane sulfonamidoethanol			x
N-Ethlyperfluorooctane sulfonamidoethanol			x
N-Ethlyperfluorooctane sulfonamido acetic acid		x	x
N-Methlyperfluorooctane sulfonamido acetic acid		x	x
1H, 1H, 2H, 2H-Perfluorohexanesulfonic acid	x		x
1H, 1H, 2H, 2H-Perfluoroctanesulfonic acid	x		x
1H, 1H, 2H, 2H-Perfluorodecanesulfonic acid	x		x
Hexafluoropropylene oxide dimer acid	x	x	x
4,8-dioxa-3H-perfluorononanoic acid	x	x	x
Nonafluoro-3,6-dioxa-heptanoic acid	x		x
Perfluoro(2-ethoxyethane)sulfonic acid	x		x
Perfluoro-3-methoxypropanoic acid	x		x
Perfluoro-4-methoxybutanoic acid	x		x
Perfluoro(3,5-dioxahexanoic) acid			x
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	x	x	x
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	x	x	x
Perfluoro (2-ethoxyethane) sulfonic acid	x		x
3-Perfluoropropyl propanoic acid			x
2H, 2H, 3H, 3H-Perfluorooctanoic acid			x

Panel Comments

The Panel agrees with the Project Team's approach.

Note that Perfluoropropane sulfonic acid (3-carbon PFAS) is not included in EPA method 533, 537.1, or in Draft Method 1633.

The reproducibility, detection limit, and extraction recovery of short-chain PFAS (4-carbon and shorter PFAS) are poor in all three methods. The Draft EPA Method 1633 added long-chain PFAS (8-carbon chain and longer PFAS) that are not expected to be in the treated wastewater because they will effectively sorb on the GAC.

The proposed MCL does not include long-chain PFAS. It would be useful to send samples to a research lab that can optimize for the analysis of short-chain PFAS at a lower detection limit with better reproducibility.

MDE Comment

8. The pilot plant should be monitoring and reporting settled water turbidity and have a turbidity standard of 1 NTU 95% of the time. Turbidity readings should be reported for each individual sedimentation basin (if multiples are present in the pilot plant) as well as each individual biofilter. Turbidity readings should be collected at least every minute to be sure that all spikes are captured (not sure if they are just recording turbidity every 15 minutes).

Project Team Response

The pilot system is equipped with a total of ten online turbidimeters, which continuously measure turbidity levels at various critical points within the system. However, the data logging system is configured to record these turbidity measurements at intervals of 5 minutes to effectively manage data storage.

These points include:

Tertiary effluent (pilot influent)	BAF Column #4
Settled water (pilot consists of one sedimentation tank)	GAC Column #1
BAF Column #1	GAC Column #2
BAF Column #2	GAC Column #3
BAF Column #3	GAC Column #4

The statement made in the report: "Additional removal credit can also be achieved by maintaining an individual filter effluent turbidity level of 0.15 NTU 95% of the time, having no two consecutive measurements 15 minutes apart greater than 0.3 NTU, and a combined filter effluent of 0.15 NTU 95% of the time" refers to the SWTR monitoring requirement which requires turbidity to be monitored continuously and recorded at least every 15 minutes (US EPA, 2020).

Additionally, the 10 State Standards use the same turbidity monitoring frequency (every 15 minutes). Notably, the pilot monitoring regime significantly surpasses this requirement and the EPA's monitoring requirements.

Furthermore, the pilot team conducts weekly grab samples to validate the accuracy of the online instruments. Simultaneously, regular weekly cleaning operations are performed to prevent potential obstructions caused by settled particles or biological growth, ensuring consistent high-quality data collection. The team engages in monthly calibration exercises to uphold the precision of these measuring instruments.

A snapshot of the data presented in Figure 6 of the report indicates tertiary effluent turbidity is in the 0.6-1.2 NTU range; settled water turbidity has been maintained below 0.4 NTU, well below the suggested limit of 1 NTU. Additionally, the current average turbidity in the BAF columns is 0.17 NTU.

Panel Comments

No comment on this issue.

MDE Comment

9. Page 10, Table 7. It mentions "For the whole duration of the study, poor floc settling has been an issue.... the pilot team has observed frequent floc carryover to ozone and biofiltration." As a remedy, "The pilot team is considering running bench-scale dissolved air flotation experiments to determine if the solids present would float better than settle." The pilot study should continue until truly stable, consistent and acceptable performance for a full year (maybe 2 years??). This can be achieved for all unit processes regardless of water quality changes in incoming treated wastewater.

Project Team Response

It should be noted that the objective of pilot-scale treatment is to determine the optimal operating scenario and treatment regimes to meet the treatment goals. Thus, unexpected findings often occur and changes in plans are required and developing strategies to mitigate those challenges is a primary purpose of piloting. Some of the challenges associated with poor floc settling are due to the very high-quality water produced at the Patuxent WRF which serves as the pilot system influent. Other challenges are due to minor, but real, hydraulic variations that may occur when scaling unit processes down to the pilot-scale. It is widely accepted that demonstration and full-scale processes exhibit higher levels of robustness relative to pilots.

As discussed in previous responses, monitoring is a key risk mitigation strategy and focus of the Anne Arundel County project team. In a demonstration or full-scale system, the CCPs developed during piloting will determine when processes should be taken offline, that is, when water is not injected into the aquifer and instead redirected to the current facility discharge location. Appendix B, Table 14 shows the average, minimum and maximum concentrations in the finished water. The treatment goals in the finished water are still being met despite operational challenges with the floc/sed pilot.

The filter effluent turbidity values are below 0.3 NTU and are in compliance with the SWTR. Current efforts are focused on optimization of the coagulation and floc/sed process to further improve turbidity and TOC removal and does not mean that existing operation cannot meet the AWT goals.

Operation of the pilot system will continue with input from MDE and the ISAP until we have confidence that the treatment processes are optimized. The next step in the overall program would be to design and build a demonstration plant that will inject high quality drinking water into the Lower Patapsco and Patuxent aquifers for sufficient duration to verify that the water quality meets all CCPs, all SDWA requirements, and does no harm to the aquifer.

Panel Comments

The Panel notes that the individual filter effluent (IFE) and combined filter effluent (CFE) turbidity of <0.15 nephelometric turbidity units (NTUs) is the goal, and while test results are not there yet, settled water turbidity likely affects meeting the IFE and CFE objectives.

The Panel also notes that this is a pilot investigation and that full-scale operations may not exhibit similar turbidity issues because of better hydraulic function. The Panel recommends a full evaluation of the pilot system performance to determine if components of the system are contributing to turbidity.

Anne Arundel County should consider testing ferrate as a coagulant, which yields better results compared to ferric chloride and other chemicals. The concentration of ferrate may be 10 percent compared to ferric chloride; it also tends to bind the lower molecular weight components of TOC and acts as a disinfectant.

MDE Comment

10. Page 11, Table 7. It states, "Pressure builds up in the filtration columns has periodically led to partial replacement of either BAF or GAC media when the media." It appears these processes are not operating as expected or as needed and are clogging rapidly, potentially due to insufficient treatment upstream in the pilot plant.

Project Team Response

Pilot BAF and GAC systems consist of pressurized columns as opposed to gravity filter beds often used in full-scale operation. Due to the small-scale design and geometry of the pilot columns, media loss during backwashing can occur in pilot systems and is not unexpected. This is sometimes caused by column wall effects that lead to conglomeration of media during backwashing. Full-scale filter and contactor configurations rely on optimized backwash distribution systems and launder designs that minimize media loss for a given application. These features are not practical (or available) for a pilot-scale filter/contactor skid.

These wall interactions do not typically occur in demonstration or full-scale designs, which will most likely be gravity filter and contactor configurations. Pilot media loss is commonly observed and is not related to upstream treatment or clogging of media. As mentioned in Table 7, media losses have been minimal and impacts to water quality data have not been observed.

Panel Comments

No comment on this issue.

MDE Comment

11. The performance of the proposed AWT treatment train is dependent on an expected range of influent concentrations to the AWT. New or changed discharges of contaminants of concern into the sewer system can significantly impact the influent concentrations of various contaminants, and consequently the discharge levels. A pilot study may or may not encounter this condition or conduct the monitoring during such an event. So, no matter the precautions there is a risk associated with the carbon system that is not present with a membrane-based treatment method.

Project Team Response

Carbon-based systems have been used in several IPR systems for their resilient nature and robust treatment capabilities. Gwinnett County, GA; Hampton Roads, VA; and Upper Occoquan, VA all use ozone-biofiltration system for IPR. Furthermore, carbon-based systems have been compared to membrane-based systems in two major water reuse studies: WRF Reuse 15-11 Project (Gwinnett County, GA) (Funk et al., 2018) and the HRSD SWIFT Pilot (Vaidya et al., 2021).

Findings from these studies have demonstrated the robust nature of both treatment approaches and differentiated the advantages and disadvantages of each approach. Generally, membrane-based treatment systems are ideal for reuse scenarios that require total dissolved solids reduction with access to manageable concentrate treatment options.

Furthermore, every system can fail, and membranes are no exception to this rule. There have been studies showing the breakthrough of contaminants, such as short-chain PFAS through RO and NF membranes (Bates et al., 2023). Additionally, biofouling is common in RO membranes and can result in membrane failure, downtime, and reduced useful life of membranes (Hoek et al., 2022).

The most practical and effective approach to minimize the risk of sewershed discharges on AWT influent water quality for any treatment approach is to employ multiple monitoring points and barriers to assess and mitigate these releases. The AWT treatment approach proposed by the County includes both.

Piloting is conducted to better understand upstream upsets or variability in source waters; however, it is impossible to capture every source water scenario. Rather, risk reduction should be the primary focus of potable reuse systems to combat future water quality uncertainties. Risk reduction strategies include multiple approaches that the Anne Arundel County Team is utilizing or will utilize in the future:

- Multi-barrier treatment: The AWT pilot treatment process consists of a multi-barrier approach to remove contaminants and achieve finished water treatment goals.
- Online Monitoring: Continuous monitoring of AWT influent and within the AWT process is used to identify upsets and spikes in the contaminants.
- Industrial Pretreatment Program and Source Control: The County is working on a pretreatment program to help detect contaminants in sewersheds. For example, sources of PFAS can be identified ahead of the WRF and treated or mitigated at the source if possible.
- Third Party Monitoring: The HRSD SWIFT program appointed independent labs for monitoring and confirming their existing data. This level of redundancy in water quality analysis can be implemented at the demonstration or full-scale facility.
- CCPs: As explained in the section ‘Risk Reduction and Use of Critical Control Points’, online monitoring will help in taking corrective action such as diverting water from injection once the water quality parameters exceed the threshold limits.

Panel Comments

The Panel notes and concurs with the Project Team's plans to implement a source control and pretreatment program to help detect contaminants before they reach the AWT plant.

MDE Comment

12. Page 9, Table 6. The Results and Less Learned column indicates "awaiting testing" for the results of the performance of the granular activated carbon. The Testing Completed column indicates "Rapid small-scale column testing has been designed and is currently in assembly". Please forward this information to MDE, when available.

Project Team Response

We will provide the data as it is accumulated.

Panel Comments

No comment on this issue.

MDE Comment

13. Page 10, Table 7. The "worms from WRF effluent" row indicates worms clogged the pilot feed strainer, which caused a flocculation and sedimentation shutdown. Weekly strainer cleanings were performed to mitigate this. This process needs a lot of upkeep in order for it to perform well.

Project Team Response

The presence of algae, as well as red worms or Midge fly larvae, stemmed from a nutrient issue upstream, which the WRF has taken measures to address. These challenges prior to entering the pilot treatment processes and would be disruptive to any downstream treatment process, including membranes. This study demonstrates the benefits of pilot testing as an opportunity to characterize and mitigate upstream process challenges prior to demo- and full-scale implementation.

The pilot study has played a pivotal role in comprehending the seasonal variations occurring in the wastewater effluent, which serves as the influent feed for the pilot system. Despite upstream changes in water quality, the pilot has maintained excellent finished water quality through the duration of the study. As is common in any treatment process, regular maintenance and appropriate pretreatment are essential to ensure the continuous performance of the system.

For instance, during warmer weather, the WRF experienced a period of heightened algae and red worm growth. This realization prompted the WRF to reduce the mixed liquor recycle rate to optimize nutrient reduction in the secondary treatment process. The pilot team also responded with a controlled addition of sodium hypochlorite (~0.5 mg/L) to the AWT influent feed tank and a scheduled weekly cleaning of the strainer. No changes to disinfection byproduct formation were observed, as all of the chlorine was consumed in the biofilters.

Given the pilot system's size, a basket strainer with a fine screen opening has been implemented at the system's front end to safeguard downstream equipment. While strainer clogging due to both algae and worms is a concern at the pilot-scale, it's worth noting that this issue might not necessarily translate to the full-scale system due to differences in size and capacity. In a full-scale operation, employing a strainer with an automatic cleaning process could potentially eliminate this concern.

The “Biological Overgrowth in Upstream WRF” row indicates an overgrowth of gelatinous biofilm clogged the influent line feed of the pilot. The overgrowth forced a shut down when the feed pumps failed because of this. The staff have to aggressively clean the pre-ultraviolet channel and cover the channel with a tarp.

For the entire duration of the study, poor floc settling was an issue. The pilot required weekly manual cleanings to reduce residual carryover.

As noted in Comment 13, the AWT pilot provides an opportunity to stress-test the treatment system for a range of influent water conditions. While the pilot team have observed inter-process treatment issues (such as additional cleaning needs and floc carryover), the overall treatment goals of the pilot are still being met. The pilot team is currently focused on making small adjustments to pilot treatment to reduce these observations.

Panel Comments

The Panel notes that this issue is not expected to occur in the full-scale plant.

Regarding the comment, “No changes to disinfection byproduct formation were observed, as all of the chlorine was consumed in the biofilters,” the Panel notes that pre-chlorination here would not provide enough residual to persist through flocculation and sedimentation. The Panel advises against adding chlorine to a biofilter, particularly if N-Nitrosodimethylamine (NDMA) removal is a goal.

MDE Comment

14. Page 19, Table 10. The footnote indicates legionella data requires additional testing due to contamination during sampling. Sampling procedures need to be revised to avoid contaminations. Please update the legionella data, when available.

Project Team Response

Agree with the reviewer's comment. The contamination event is being investigated through additional *Legionella* testing, with the next sampling event occurring in September.

Panel Comments

The Panel agrees with MDE and the Project Team.

MDE Comment

15. Page 20. The paragraph below Figure 10 indicates data validation is needed to determine whether a log reduction value of a 6-log reduction for oocysts can be achieved. Please update the oocysts validated data, when available.

Project Team Response

The treatment goals for the pilot include 4-log reduction of enteric viruses and 6-log reduction of *Cryptosporidium* oocysts and *Giardia* cysts.

According to Table 1.4 of the UV Disinfection Guidance Manual for the Final LT2ESWTR shown below, a 4-LRV of enteric viruses is accomplished by a UV fluence of 186 mJ/cm^2, greatly exceeding the fluence needed for 6-LRV of *Cryptosporidium* and *Giardia*.

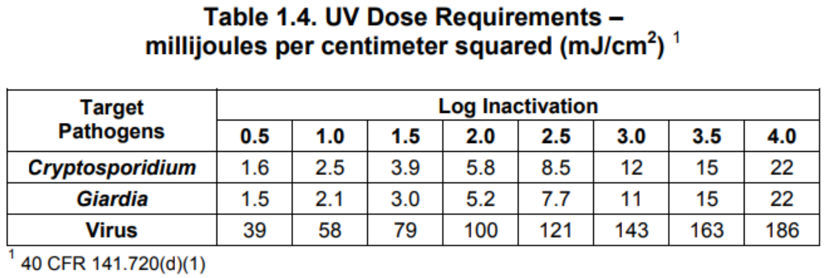

Table 1.4. UV Dose Requirements – millijoules per centimeter squared (mJ/cm^2) [1]

Target Pathogens	Log Inactivation							
	0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

[1] 40 CFR 141.720(d)(1)

Figure 10 of the Mid-term AWT Pilot Memorandum shows MS2 reductions up to 7.52 LRV were observed during initial UV testing. Using the relationship between MS2 reduction and UV fluence presented in Figure 1 of the NWRI UV Guidelines, a 7.5 LRV of MS2 corresponds to a Reduction Equivalent Fluence (REF) of 190 mJ/cm^2. This data suggests that the UV system can meet all UV pathogen reduction goals; however, the authors would like to perform additional validation testing to confirm initial test results. Additional validation data, including *Cryptosporidium* oocyst data, from September testing will be provided.

It should be noted that the ViQUA PRO20 UV system used for the pilot is NSF/ANSI 55 validated and any UV reactors considered for full-scale design will be USEPA validated for the proposed fluence range.

Panel Comments

The Panel agrees with the response from the Project Team.

MDE Comment

16. Page 24. It mentions PFAS breakthrough in the GAC process. It appears PFAS is not removed effectively when granular activated carbon media ages. Please include an operational procedure to avoid the PFAS breakthrough.

Project Team Response

Please refer to Comment 4.

It is important to note that even though PFAS breakthrough occurred in GAC after many bed volumes, the effluent PFAS concentrations were well below the EPA proposed MCLs. Effluent GAC PFAS concentrations were also below the AWT influent PFAS concentration, indicating that PFAS are still being removed by GAC.

An operational strategy of replacing GAC media will be implemented when effluent PFAS concentrations approach EPA proposed MCLs, standards set by the MDE, or exceedance of influent PFAS concentrations.

Panel Comments

The Panel agrees with the Project Team. This is fundamentally how an adsorption-based process like GAC works. As stated, a properly designed GAC system, with lead and lag vessels or multiple vessels operating in parallel with frequent monitoring, are the industry standard for PFAS removal. The Panel agrees with the Project Team.

MDE Comment

17. Page 40, Table16. The average effluent PFOA and PFOS concentrations determined from TE (tertiary effluent), OZE1 and OZE2 (Ozone Contactors 1 and 2) samples indicate an increased trend of PFOA and PFOS concentrations among these three sampling locations. It appears that the ozonation process generated PFOA and PFOS. Please share the causes of this increasing trend, if known.

Project Team Response

Ozone is a strong oxidant that can oxidize and transform existing PFAS precursors (compounds like fluorotelomer alcohols and fluorotelomer sulfonates) into PFAS “end products”, also referred to as “terminal perfluoroalkyl acids (PFAAs)” like PFOA and PFOS. Terminal PFAS do not transform further. This transformation of PFAS precursors is commonly observed in drinking water, reuse and even wastewater treatment plants.[6]

It is important to note that even though PFOA and PFOS concentrations increased during ozonation, they were removed by the downstream GAC process and were below the EPA proposed MCLs of 4 ng/L. Other oxidative processes may also produce terminal PFAAs (persulfate, advanced oxidation, etc.).

Panel Comments

Ozone and biological activated carbon (BAC) with downstream GAC has been demonstrated to be an effective multiple barrier treatment system. The HRSD SWIFT project, among many others, is a good example of successfully using Ozone/BAC with downstream GAC.

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[6] Kumar, P., Rodriguez-Gonzalez, L., Salveson, A., Ammerman, D., & Steinle-Darling, E. (2021). Per- and polyfluoroalkyl substance removal in carbon-based advanced treatment for potable reuse. *AWWA Water Science*, *3*(5), e1244. https://doi.org/10.1002/aws2.1244

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Appendix A • About NWRI Panels

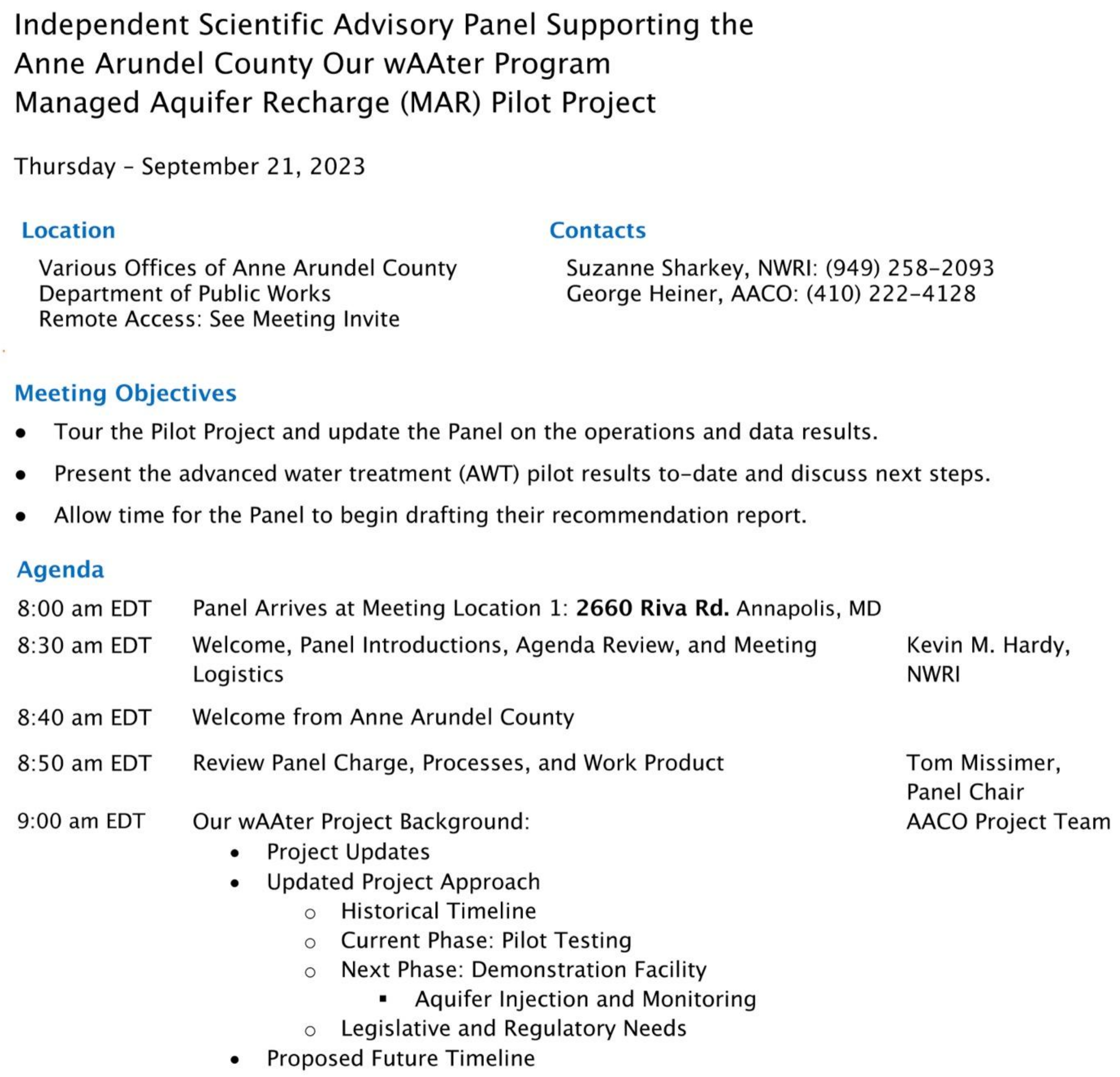
NWRI Independent Advisory Panels are independent teams of internationally recognized experts that review challenging water resources management, policy, and investment issues. This process leads to decisions that are grounded in science and best practices. NWRI-facilitated Panels serve cities, counties, special districts, joint powers agencies, government agencies, nongovernmental organization partners, and private firms.

We have administered hundreds of Panel meetings across the country on topics that include water treatment and reuse infrastructure planning; design, commissioning, monitoring, and operations; groundwater quality and recharge management; surface water quality and reservoir design improvements; and a growing body of potable reuse policy guidance across the country.

NWRI Panels provide:

- Independent, third-party review and evaluation.
- Scientific and technical advice by relevant, leading industry experts.
- Help and support with challenging scientific questions and regulatory requirements.
- Reports on status, progress, findings, and recommendations as required by the engagement.
- Support in interactions with the public, decision makers, and regulators.

Appendix B • Meeting Agenda



Independent Scientific Advisory Panel Supporting the Anne Arundel County Our wAAter Program Managed Aquifer Recharge (MAR) Pilot Project

Thursday – September 21, 2023

Location

Various Offices of Anne Arundel County
Department of Public Works
Remote Access: See Meeting Invite

Contacts

Suzanne Sharkey, NWRI: (949) 258-2093
George Heiner, AACO: (410) 222-4128

Meeting Objectives

- Tour the Pilot Project and update the Panel on the operations and data results.
- Present the advanced water treatment (AWT) pilot results to-date and discuss next steps.
- Allow time for the Panel to begin drafting their recommendation report.

Agenda

8:00 am EDT	Panel Arrives at Meeting Location 1: **2660 Riva Rd.** Annapolis, MD	
8:30 am EDT	Welcome, Panel Introductions, Agenda Review, and Meeting Logistics	Kevin M. Hardy, NWRI
8:40 am EDT	Welcome from Anne Arundel County	
8:50 am EDT	Review Panel Charge, Processes, and Work Product	Tom Missimer, Panel Chair
9:00 am EDT	Our wAAter Project Background:	AACO Project Team

- Project Updates
- Updated Project Approach
  - Historical Timeline
  - Current Phase: Pilot Testing
  - Next Phase: Demonstration Facility
    - Aquifer Injection and Monitoring
  - Legislative and Regulatory Needs
- Proposed Future Timeline

9:50 am EDT	AWT Pilot Midterm Results • AWT Pilot Treatment Goals ○ Treatment Efforts to Date ○ Future Optimization • Monitoring Strategies & Data Accumulation • Pilot Results to Date • Data Gaps/Future Research ○ Academic Partnership • Risk Reduction Strategies	AACO Project Team
11:00 am EDT	Drive to Pilot Facility: **1640 Professional Blvd.** Crofton, MD	
11:15am EDT	Tour Patuxent Water Reclamation Facility	
12:00 pm EDT	Drive to Meeting Location 2: **445A Maxwell Frye Road** Millersville, MD	
12:20 pm EDT	Working Lunch	
12:30 pm EDT	Open Technical Discussion • TOC Treatment Objectives • RO vs. Carbon Based Treatment • Groundwater Compatibility • Carbon and PFAS • Pathogen Removal Credits • Discuss Next Steps	AACO Project Team
1:45 pm EDT	Final Panel Q & A	Kevin Hardy, NWRI
2:00 pm EDT	Panel Closed Working Session	Tom Missimer, Panel Chair
3:00 pm EDT	Adjourn	

Appendix C • Attendees

NWRI Panel Members

Chair: Tom Missimer

Diana Aga

Charles Bott

Mehul Patel

Steve Via

AACO Project Team

Christina Alito, HDR

Brian Balchunas, HDR

Sharon Cole, AACO

George Heiner, AACO

Karen Henry, HDR

Larry Hentz, HDR

Mamatha Hopanna, HDR

Kelsey Kenel, HDR

Rob Kraus, AACO

Chance Lauderdale, HDR

Chris Murphy, AACO

Beth O'Connel, AACO

Tara Randall, HDR

Ramola Vaidya, HDR

Maryland Department of the Environment

Greg Busch

Zoe Goodson

Janet Hartka

Alex McNamee

Ching Tien

Chris Watling

NWRI

Kevin Hardy

Mary Collins

Tianna Manzon

Suzanne Sharkey

Other Attendees

Julie Minton, WRF