Summary of Maryland's PFAS Scientific Roundtable

October 5, 2020

University of Maryland Center for Environmental Science

Maryland Department of the Environment

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Executive Summary

The Per- and Polyfluoroalkyl Substances (PFAS) Science Roundtable sponsored by the University of Maryland Center for Environmental Science (UMCES) in cooperation with the Maryland Department of the Environment (MDE) was held on October 5, 2020 from 9:30 a.m. to 2:30 p.m. with over 20 scientists and PFAS experts from academia, six federal agencies, and the states of Pennsylvania and Delaware. The purpose of the Roundtable was to:

- Discuss the state of the science around PFAS (e.g., toxicity, exposure, fate and transport of PFAS in the environment, analytical methods and treatment technologies);
- Highlight the actions MDE has taken and is taking to better understand, communicate and manage PFAS risks; and,
- Obtain scientific input on PFAS priorities in Maryland moving forward.

There were several overview presentations in the morning about PFAS toxicity, exposure, fate and transport, analysis, and treatment, as well as ample time for discussion among attendees throughout the day.

Key observations from the convened scientists included:

1. The importance of first focusing on understanding and characterizing the occurrence of PFAS throughout the State of Maryland.
   - Experts reassured that MDE's focus on investigating military installations, sampling public water systems for PFAS, and broadly studying fish tissue across the State is a solid start.
   - Experts recommended MDE continue work to characterize the Maryland "PFAS Footprint." States are impacted by PFAS in differing ways. Identifying, categorizing, and managing PFAS sources early can create meaningful reductions of PFAS concentrations in the environment in the future.

2. There are still many unanswered questions of PFAS science, but it is an active area of research largely funded by federal agencies (e.g., the Department of Defense, the Environmental Protection Agency, the National Science Foundation, and, the Centers for Disease Control) with many emerging studies being published.
   - Questions concerning the following topics need to be explored further: toxicity, fate and transport, degradation of PFAS in the environment; human exposure and the most significant pathways; treatment effectiveness; and obtaining accurate measurements of PFAS in various materials.

3. When studying or managing PFAS in the environment - during drinking water treatment, or at cleanup sites - a number of variables must be accounted for to optimize efforts.
   - Differences in environmental/human health risk and behavior in the environment exist between different PFAS compounds. Properties such as chain length, functional group, amount of fluorine bonding, and others all need to be accounted for when designing studies and/or cleanup efforts. For example, water treatment plants' (WTPs) use of

Granular Activated Carbon (GAC) filters may not be the most effective treatment method for shorter chained PFAS compounds as they tend to “break through” quicker and are often more mobile (but potentially less toxic) than their long chain counterparts.

4. Experts suggested MDE consider several priorities during their next wave of PFAS-investigative work.

- These priorities include investigating the occurrence of PFAS: (a) in effluents of Wastewater Treatment Plants (WWTPs) and in biosolids; (b) at landfills and in their leachate; and (c) at locations where there is some evidence of a large amount of PFAS-containing products or materials processed from the past.

5. Experts also suggested MDE investigate some uniquely Maryland issues which may not be covered by science done elsewhere.

- Maryland-specific investigations are likely to include: (a) “unique” food sources or consumption patterns in Marylanders (e.g., relatively high consumption of blue crabs); (b) "recycling" of crab shells as fertilizers and potentially use in animal feed; and (c) the impact of the freshwater, estuarine, saltwater "gradient" on the occurrence and transformation of PFAS in water and degree of bioaccumulation in aquatic organisms.

6. MDE should explore the occurrence of PFAS in groundwater as it is used as the primary drinking water source in some areas of the State – such as on the Eastern Shore.

- PFAS may move from human waste through septic systems and the application of biosolids onto agricultural land and into the drinking water wells and irrigation systems. It was noted that areas that have utilized biosolids for decades may be of particular interest, as biosolids applied prior to 2001 likely had more perfluorooctanoic acid (PFOA) and perflourooctane sulfonate (PFOS) than what is currently being found in biosolids. This is due to the voluntary phase out of PFOA/PFOS by U.S. companies in 2001.

Because of ongoing and planned toxicity testing at the federal level, the convened scientists did not suggest that conducting human health-related toxicity testing of PFAS compounds (i.e., for the many PFAS currently lacking toxicological endpoints) be a priority for the State. In addition, the convened scientists did not suggest that Maryland place any emphasis now on air emissions/releases as a priority pathway of human exposure to PFAS within the State.

MDE looks forward to working collaboratively with multiple partners to garner a better understanding of PFAS sources and risks as well as the remediation of impacted areas with the goal of reducing the short- and long-term risks to Maryland’s citizens. These studies will need to be carefully designed and will require funding, enhanced expertise, and strategic partnerships within and beyond the State to complete.

THE PFAS SCIENTIFIC ROUNDTABLE

Working collaboratively, the University of Maryland Center for Environmental Science (UMCES) and the Maryland Department of the Environment (MDE) hosted a virtual meeting to discuss the state of per- and polyfluoroalkyl substances (PFAS) science, address existing data gaps and concerns, and explore recommendations for future PFAS work in Maryland to be most protective of human health. Local and national experts from academia, federal agencies, and State officials gathered for this discussion to speak about their previous PFAS work and provide insight and suggestions on MDE's recent and future PFAS work. Regional state agency experts from Delaware and Pennsylvania were also invited because of their recent experiences in considering PFAS monitoring and assessment needs.

This session included presentations from several academic and agency scientists, highlighting their work to better understand the chemistry, bioaccumulation pathways, remediation technologies, and potential impacts to human health of PFAS compounds. MDE also presented its current understanding of local sources as well as current and future monitoring and assessment plans related to PFAS so that the assembled experts could provide advice to the State. The list of participants is compiled in Appendix 1 of this report.

After the presentations, a facilitated discussion focused on the following two questions:

1. What are the most important data gaps and/or unanswered questions regarding PFAS and its impacts on human and environmental health?
2. Understanding MDE's priorities thus far, what are the recommendations for future work in Maryland as MDE moves forward to better understand, communicate and manage unacceptable PFAS risks?

While the presentations and discussion were at a high scientific level, this summary has been drafted by MDE and UMCES to read at a level for the interested public, agency leadership, and other government officials, including elected representatives. This summary was reviewed by the participants to ensure this document accurately captures the PFAS topics, data gaps, and recommendations for MDE discussed during the event.

WHAT ARE THE PFAS CLASS OF CHEMICALS?

PFAS are a group of human-made chemicals that include: PFOA, PFOS, and GenX (GenX is a trademark name for a short-chain organoflourine compound) and over 4,000 other variants[1]. Used since the 1940s, chemicals in the PFAS family are in a number of commercial and industrial products and processes due to their surfactant and dispersant properties, chemical and thermal stability, and their ability to resist heat, water, and oil[2]. Common uses of PFAS in consumer products and industrial processes include, but are not limited to: firefighting foams, chemical processing, building and construction, electronics, cooking surfaces, fabric and packaging coatings, and much more[3].

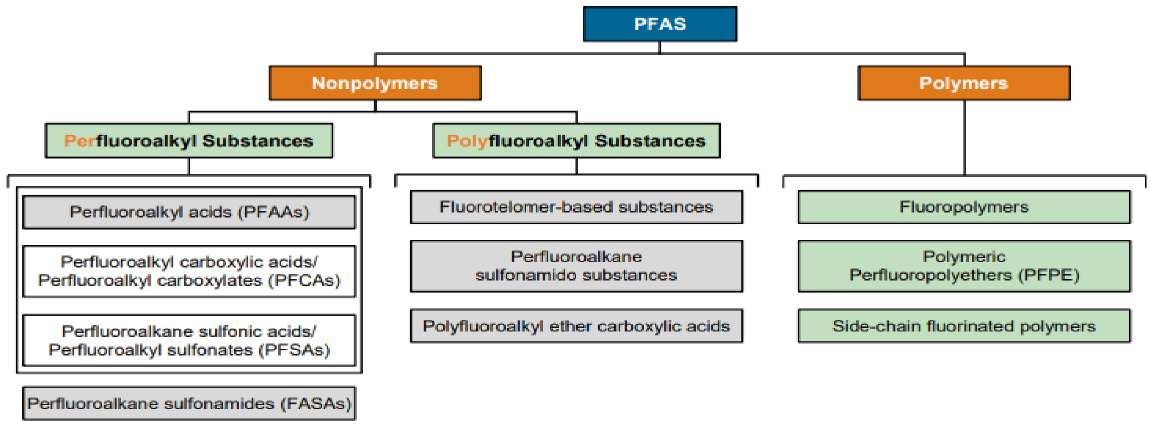

Figure 1. Classes of PFAS[3]

BRIEF OVERVIEW OF PFAS NAMING CONVENTIONS

The term PFAS refers to a large group of over 4,000 human-made compounds. All PFAS compounds vary from one another by carbon chain length, the amount of fluorines bonded to the chain, and/ or functional group. Broadly, PFAS compounds can be divided into two classes: non-polymer and polymer species. Non-polymer PFAS contain two classes: per- and polyfluoroalkyl substances. These two groups contain many subgroups within them. These compounds are most commonly detected in humans and the environment and are summarized in Figure 1.

Perfluoroalkyl Substances

Perfluoroalkyl substances are those compounds where each carbon in the chain is attached to a fluorine (outside of the functional group). The majority of the discussions during this event focused on perfluoroalkyl acids (PFAAs) and the degradation of polyfluoroalkyl acids to PFAAs.

Perfluoroalkyl acids

PFAAs are the most commonly tested compounds in the environment. PFAAs are often referred to as "terminal degradation products," because these compounds do not undergo any known degradation in naturally occurring conditions. Common PFAAs include: PFOA, PFOS, perflourobutane sulfonate (PFBS), perflourohexane sulfonate (PFHxS), and others.

Polyfluoroalkyl Substances

Polyfluoroalkyl substances differ from perfluoroalkyl substances because not every carbon in their chain is attached to a fluorine. In polyfluoroalkyl substances, carbon atoms typically attach to hydrogen and oxygen. Polyfluoroalkyl substances can degrade into perfluoroalkyl substances, making PFAS treatment and remediation difficult to manage.

Polymer PFAS

Polymer PFAS are larger molecules formed by combining smaller molecules in a repeating pattern. Polymer PFAS typically pose less human and ecological threats than their non-polymer counterparts.

PFAS USES AND SOURCES IN MARYLAND

While certain PFAS chemicals are no longer manufactured in the United States (i.e., PFOA and PFOS), they are still produced internationally and can be imported in consumer goods such as carpets, textiles, coatings, packaging, cookware, rubber and plastics.

Common releases of PFAS to the environment can be attributed to the following:

- Industrial sites producing or using PFAS (i.e., manufacturing sites);
- Areas where Aqueous Film-Forming Foams (AFFF), used in fire retardants, have been used;
- Effluent and biosolids from Wastewater Treatment Plants (WWTPs);
- Areas where biosolids have been applied; and
- Landfills, including leachate, impacting surrounding soils and underlying groundwater (if landfill is unlined and/or if runoff occurs).

Little is known about the historical use of PFAS compounds throughout the State. However, there are some areas in the State that may be prone to higher concentrations of PFAS in their soils, groundwater, and other environmental media due to the use of PFAS-containing products. Examples of documented sites of PFAS release include fire training areas and military installations where PFAS-containing AFFF has been or is currently being used.

Do all PFAS chemicals behave the same way in the environment and pose the same risks?

The diversity of PFAS chemical structures has important implications for their fate and transport, transformation in the environment, potential to bioaccumulate, and for treatment effectiveness. PFAS with longer carbon chains are generally more persistent in the environment, with degradation requiring years, decades, or longer. Their shorter-chained counterparts tend to be more mobile in the environment and likely less toxic.

Due to their widespread use and persistence in the environment, most people in the United States have been exposed to PFAS. Despite efforts to reduce the manufacture and use of certain longer chain PFAS in the early 2000s, legacy contamination from these particular PFAS means they remain in the environment and the toxicity of newer alternative products (i.e., shorter chain PFAS, precursor PFAS, etc.) have not been well studied. Thus, human exposure to PFAS is a continuing public health concern[4].

The majority of research on the potential human health risks of PFAS is associated with ingestion. Limited data exist on health effects associated with inhalation or dermal exposure to PFAS. Most available toxicity data are based on laboratory animal studies. There are also several human epidemiological studies of PFOA and PFOS. Exposure to some PFAS above certain levels may increase risk of adverse health effects.

While many of the same effects are observed for the family of PFAS chemicals, it appears that different adverse effects may be dominant in different PFAS. Depending on the PFAS, increased risks observed in some animal studies include[5]:

- Developmental effects to fetuses during pregnancy and infants (e.g., low birth weight, altered puberty, skeletal variations);

- Cancer (e.g., testicular, kidney);
- Liver effects (e.g., tissue damage);
- Immune effects (e.g., changes in antibody production, efficiency of medication); and,
- Thyroid effects (e.g., cholesterol effects).

Long-chain PFAS (8 carbons or more) are generally thought to present a greater toxicity threat to humans than shorter-chain PFAS, though the toxicities of short-chain PFAS have generally been less thoroughly studied. Additionally, short-chain PFAS are more mobile in soil and water. Due to increasing global production and use, environmental and human exposure to short-chain PFAS is expected to increase over time. Differences in mobility, fate and persistence in the environment, as well as treatability in environmental media across the complex family of PFAS are expected to contribute to differences in potential exposures and resulting health risks in humans.

Longer chain PFAS are more persistent in the environment than shorter chain PFAS. They can be found in sources of drinking water including surface waters, reservoirs, and groundwater. Either through contaminated water or soils, PFAS can move into food items and then be consumed by humans. Seafood in contaminated waters can bioaccumulate PFAS and when consumed by humans, may expose them to these compounds. PFAS found in biosolids, which are land applied as a soil amendment to agricultural fields, may move into groundwater or be taken up by the plants.

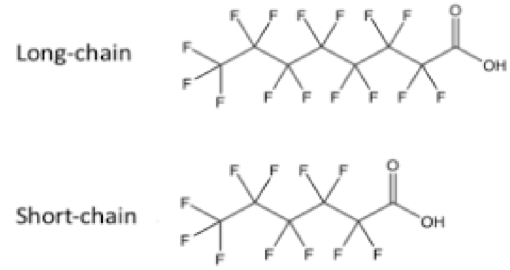

Figure 2. PFAS come in both long- and short-chains. The size of the chain can impact the environmental impact and persistence.

The occurrence of PFAS in soil, groundwater and surface water means that there are potential pathways for human exposure through drinking water and diet, including seafood consumption. In addition, the prevalence of PFAS in food packaging materials and products such as carpets and textiles used in homes provides additional potential pathways for human exposure to these compounds. It remains unclear what the most significant pathway of human exposure is to PFAS.

PFAS MILITARY INSTALLATIONS

The U.S. military still uses firefighting foams that contain PFAS chemicals to assist in rapidly extinguishing fires on airplanes and ships. PFAS are effective fire retardants because they lower the surface tension of a liquid and readily cut off the oxygen that feeds the fire. Due to repeated fire suppression training, as well as the use of the foams to extinguish fires after accidents, military bases may be areas in Maryland that are among the largest sources of PFAS and may be a local source of the release of PFAS to the air, land, and water.

The U.S. Department of Defense (DOD) has been assessing PFAS concentrations at its installations in Maryland. DOD, MDE, and

EPA have been working together to assess and monitor PFAS occurrence in order to determine if and what type of remediation is needed (see Appendix 2). So far, their work has identified eight bases where elevated levels of PFAS have been found in the soil, groundwater or nearby surface water[6]. The bases are:

1. Naval Academy, near Severn River
2. Bay Head Park, near Woods Landing
3. Fort Meade
4. Former U.S. Naval Surface Warfare Center at White Oak, near Silver Spring
5. Aberdeen Proving Ground, Aberdeen and Edgewood areas
6. Naval Air Station Patuxent River (PAX)
7. Joint Base Andrews
8. Former Brandywine Defense Reutilization and Marketing Office (DRMO)

PFAS-CONTAINING WASTES

Across the country, PFAS has also been found in effluent and biosolids from wastewater treatment systems as well as in leachate from municipal landfills. The source of the PFAS found in municipal landfill leachate is likely through the degradation of household goods. WWTPs collect wastewater from communities, treat the wastewater and then release treated water as effluent. A byproduct of wastewater treatment is biosolids, which may concentrate chemicals that are in wastewater. Many wastewater treatment plants produce biosolids which may then either be land applied to farmland as a fertilizer or sent to a landfill. It is currently unknown if biosolids in Maryland have elevated concentrations of PFAS, but this has been a concern in other states.

EPA PFAS ACTION PLAN

In February 2019, the EPA published its action plan to address PFAS compounds in the environment and the risks they pose to human health. The action plan addresses PFAS in a variety of ways, including drinking water exposure, cleanup efforts, toxicity assessments, risk communications, and more. The EPA PFAS Action Plan[7] outlines a multi-year strategy and progress summary[8].

During the Roundtable, an EPA representative presented on the progress the agency has made since the publication of the action plan and research products states can expect in the near future.

Some advances in EPA's PFAS research include:

- Updated drinking water analysis (i.e., Method 537.1, 533)
- Drafted method to analyze PFAS in surface water (SW-846, Method 8327)
- Compiled library of 430 reference samples to enable more consistent analysis of PFAS
- Updated Drinking Water Treatability Database for 26 PFAS compounds

More PFAS research from the EPA is currently underway. Appendix 4 below outlines the expected timeframe for more research products.

ACTIONS TAKEN BY MDE

MDE continues its work with DOD and EPA to assess the impacts of PFAS use at military installations. MDE is assessing the occurrence of PFAS in finished drinking water at Public Water Systems (PWSs). In addition, MDE is assessing PFAS in fish and conducted a pilot study of PFAS in oysters, as well as surface water.

Work with Military Installations
As a result of a 2018 DOD study and additional follow-up investigations, PFAS compounds were detected in groundwater at or around eight federal facilities in Maryland. MDE's Land and Materials Administration has played an integral role in approving site investigation work plans, reviewing sampling results, and communicating findings with other MDE programs.

Preliminary assessments will likely be finished at several military sites in Maryland by early summer 2021. Several other facilities are in the site investigation or remedial investigation stages (see Appendix 3). These assessments have shown PFAS detections in groundwater, soils, and surface waters in and around military installations, with the most commonly suspected source of contamination from AFFF release.

St. Mary's River Pilot Study
In 2020, MDE designed and implemented a pilot study of the occurrence of PFAS in surface water and oysters in proximity to PAX River and Webster Field military bases. Fourteen PFAS analytes were measured in oyster tissue and surface waters at multiple sites in proximity to the bases and found low levels of PFAS in surface water samples and one oyster sample from a reference site. More information on the pilot study can be found here.

Mapping of Potential PFAS Sources of Release in Maryland
In late 2019 and 2020, MDE compiled a GIS database of over 2,000 potential sources of PFAS. These sources include: WWTPs, landfills, military installations, EPA Brownfields, and others. As new potential sources are identified, they are incorporated into this database.

To determine which potential sources of PFAS may be impacting drinking water supply sources, a 1,000-foot buffer is drawn around each point source. Source protection areas for Maryland's public water systems (PWS) were mapped as well, and if a protection area intersected a potential source of PFAS, then that system was marked as potentially at risk for PFAS contaminations.

Public Drinking Water Sites
Beginning in 2019, MDE designed and began implementing a study of PFAS levels in finished drinking water at 137 PWS treatment plants across the State. High priority locations for sampling were identified based on proximity to potential sources of PFAS to the source water. The testing will continue into early 2021 with MDE taking actions as necessary to reduce risk where results indicate exceedances of the EPA Health Advisory (HA) limit of 70 ppt. MDE will consider the results of this first phase of testing, which may include sampling at additional PWSs.

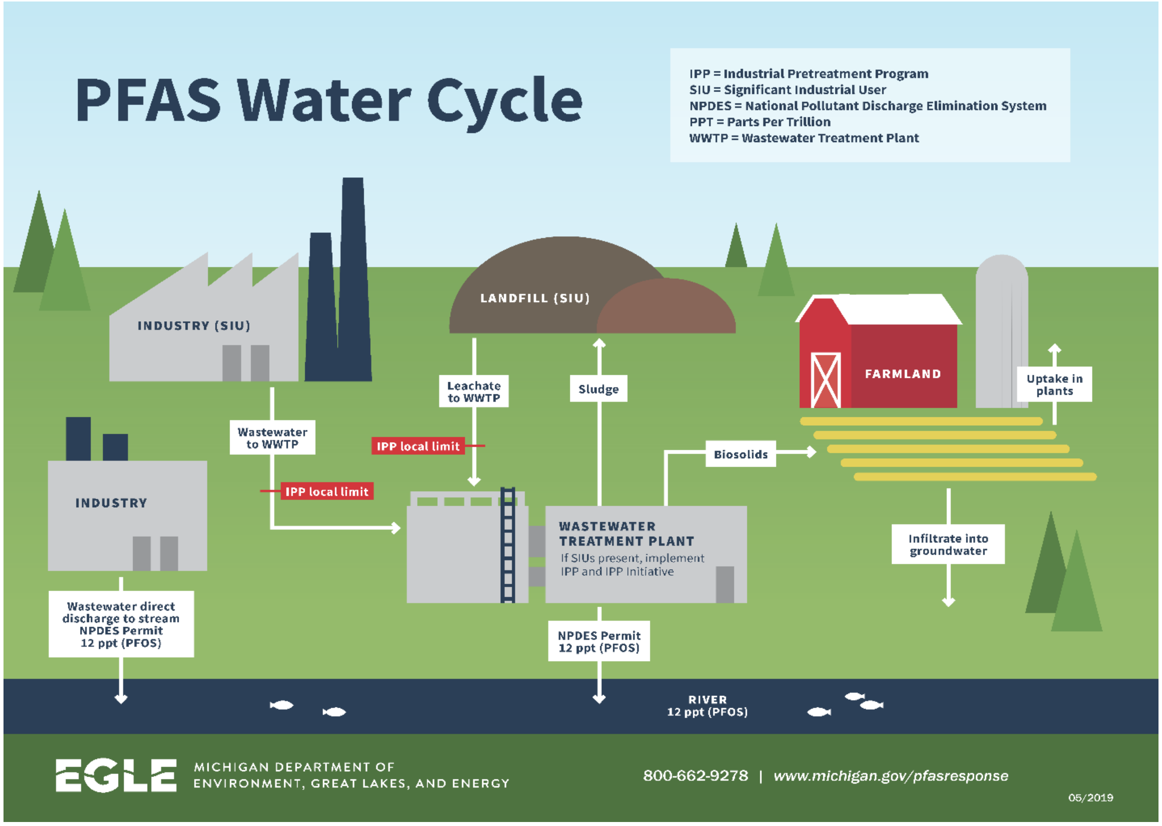

Figure 3. PFAS is diluted in water and travels with it[9]

Fish Tissue Sampling

In late 2020, MDE added PFAS compounds to the list of analytes it measures in its recreational fish monitoring program. Fish tissue sampling for PFAS will begin this year at 10-12 locations and continue at 10-12 locations per year for a total of five years to cover the various regions of the State. These data will be used to identify additional potential sources of PFAS release as well as to issue fish advisories if levels approach or exceed those for fish consumption.

OVERVIEW: STATE OF SCIENCE AND RESEARCH NEEDS

Discussions at the Roundtable focused on the following four main areas of PFAS:

1. PFAS Fate, Transport, and Bioaccumulation;
2. PFAS Treatment and Remediation Approaches;
3. Measuring PFAS; and
4. PFAS and Human Health.

PFAS Fate, Transport, and Bioaccumulation

As with any emerging pollutant, the chemistry of how PFAS changes into other molecules and under what conditions need to be carefully understood. Just because it has transformed into another molecule doesn't necessarily mean it is less impactful or persistent in the environment.

Generally, PFAS enter the surrounding soils and then can make their way to underlying groundwater or nearby waterways. There have also been instances where PFAS has been released to the air at industrial sites and can deposit to the surface miles away from their point of origin, however that is not thought to be a significant or priority concern in Maryland. Figure 3 illustrates common movements of PFAS throughout the environment.

Factors such as environmental pH, organic matter content, and PFAS chain lengths all impact their movement in the environment. For example, shorter chain PFAS tend to move more quickly in the environment than longer chained molecules. Polyfluoroalkyl PFAS molecules and their precursor compounds tend to degrade in the environment into terminal molecules, which can increase concentrations in tested media (i.e., soils, groundwater, surface water, etc.).

Experts also identified that the removal of PFAS compounds from landfill leachate is imperative before the leachate reaches groundwater or WWTP. Once in the WWTP they may end up in effluent or in biosolids and re-enter the environment and potentially find their way back into drinking water or human diet.

Bioaccumulation of PFAS tends to be both compound- and organismal species-specific. Some studies have suggested that long chain PFAS accumulate more in animals; whereas, shorter chained PFAS tend to accumulate more in plants. PFAS compounds generally accumulate less in mollusks (such as oysters) than in other aquatic animals such as fish. Level of PFAS accumulation in fish serum and tissue differ (with serum levels higher than in fish muscle) as well as there are likely differences among species of fish.

<u>Identified Data Gaps</u>

Food web studies are important to better understand bioaccumulation across trophic levels. In Maryland, this may be challenging in coastal areas with varying salinity. There needs to be a better understanding of how salinity, pH, temperature and other physical and chemical variables impact the bioaccumulation of PFAS in fish and other aquatic species. Bioaccumulation tends to be very animal/plant-specific and PFAS compound-specific, making this particularly complex.

Transformation of precursor compounds needs to be better modeled and understood. Long-chain PFAS compounds are much more likely to degrade and transform into the terminal PFAS compounds, making treatment and management very difficult. Conditions under which this transformation occurs need to be better understood.

PFAS Treatment and Remediation Approaches

There are three main categories of treatment approaches when talking about PFAS remediation: phase transfer, chemical transformation, and biodegradation.

Phase transfer refers to moving PFAS from the water to another surface, or adsorbent (i.e., Granular Activated Carbon (GAC) or Ion Exchange). Benefits of this phase transfer approach include its established use in the water industry, their effectiveness in removing PFAS compounds, and their ability to be calibrated for the water system's needs. However, these systems can become costly over time.

Transformation treatment techniques use chemistry to breakdown PFAS compounds. This treatment approach can be effective in removing fluorines from PFAS' carbon chains. Unfortunately, this process can create shorter PFAS compounds in the process and is typically expensive.

Another potential form of remediation is to use bacteria that are known to take up

PFAS, which is referred to as bioremediation. Bacteria have been shown to effectively degrade persistent chemicals in the environment such as PCBs, rendering them less harmful. Ideally the PFAS will be able to be treated at its source in the water, soil, and/or sediment and bioremediation techniques may be useful in transforming PFAS into other chemicals that are less harmful and/or easier to treat.

Identified Data Gaps

Biodegradation and bioremediation involve using specialized microorganisms to metabolize PFAS compounds. Little is known about this treatment approach, especially compared to the others. Ideally the PFAS will be able to be treated at its source in the water, soil, and/or sediment. More research needs to be completed to better understand how to implement these forms of treatment. The Roundtable panelists do believe that there is promise and opportunity for further research and use of biodegradation in the future.

For specific systems or cleanup sites, knowledge of what is in the water is necessary in knowing which treatment would serve the project best. For example, GAC filters are more effective in removing longer-chain PFAS than shorter chain compounds.

Also, the concept of treatment trains should be explored at both national and local levels. Studies have shown that using multiple treatment approaches at a specific area are the most effective in PFAS removal.

Efforts are needed to compare the technical and economic performance of drinking water treatment systems that remove PFAS. Best management practices should be standardized to minimize the transformation of one PFAS compound to another that may be more dangerous or difficult to control. Measuring changes in the fluoride ion concentration may be a good tool to determine if PFAS is destroyed in treatment.

Measuring PFAS

The ability to identify and measure PFAS compounds in a larger suite of environmental media is still an emerging science. Due to the high costs associated with this analysis, continued focus should remain on those PFAS compounds that are known to be of the greatest risk to human health and the environment until more information is available on other PFAS compounds. Risk factors may include impacts on human health, persistence in the environment, and toxicity.

PFAS are found in many environmental samples at low concentrations that are close to or are at detection limits of the measuring methodology. Background contamination may also interfere with sample analysis. Interference can come from sampling (i.e., tools), laboratory settings (i.e., dust, sample carryover), and data evaluation. Differences can also exist in laboratory methods, especially in biological samples. To remedy this, the National Institute of Science and Technology (NIST) has developed a number of reference materials to assist laboratories measuring PFAS to enhance accuracy and consistency.

Identified Data Gaps

There is a tremendous need for a universal standard of analysis for PFAS in different media. In a NIST study, it was shown that laboratories tend to vary in how they handle biological samples (i.e., serums, tissues). Also, NIST's ongoing research and development of additional reference data will be needed as the demand for more analysis in media like soils, surface water, and AFFF increases.

PFAS and Human Health

Of the over 4,000 PFAS compounds, only two (PFOA, PFOS) have been thoroughly studied in terms of human health risk. In the near term, the EPA is working to better understand toxicological profiles of the following compounds: PFBS, perflourobutyrate (PFBA), perflourohexanoic acid (PFHxA), PFHxS, perflourodecanoic acid (PFDA), perflourononanoic acid (PFNA), and GenX. The toxicological uncertainty of these compounds makes it increasingly difficult to make any regulatory decisions for so many compounds.

Through the use of multisite and community level studies, the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) have been able to look at the relationship between drinking water exposure to PFAS and health outcome data (i.e., blood serum concentrations). Looking at this relationship, ATSDR can help local physicians better answer patient questions about frequency of testing and what levels mean. ATSDR has drafted public health resources, such as toxic profiles, water to serum conversion, PFAS Exposure Assessment Technical Tools, and more.

Identified Data Gaps

Toxic endpoints are only known for PFOA and PFOS. More toxicity information needs to be finalized to help better guide Maryland's and other states' PFAS efforts.

RECOMMENDATIONS FOR FUTURE WORK IN MARYLAND

At the end of the Roundtable discussion, panelists were able to share their insight on what Maryland's top PFAS priorities should be moving forward. In general, MDE should be aware of studies being published in scientific journals and reports at the federal, State, and local levels. This is especially important as it relates to identifying sources of PFAS and pathways to human exposure.

Panelists agreed that MDE's top PFAS priorities moving forward should be:

- Developing a "PFAS Footprint" for the State of Maryland;
- Investigating WWTP effluent and the impacts of biosolid application;
- Developing methods to understand PFAS occurrence in Maryland's seafood (i.e., blue crab, fish);
- Understanding Maryland's hydrological impacts on PFAS fate and transport; and
- Exploring human biomonitoring data and the relationship between exposures and measured levels in human blood in Maryland.

Developing a "PFAS Footprint" for the State of Maryland

During the Roundtable, the concept of identifying, categorizing, and managing sources of PFAS throughout the State was discussed. MDE deems this as the State's "PFAS Footprint." Each state will have its own, unique "PFAS Footprint." Individual states will experience different PFAS sources and levels of occurrence. Some states may be more impacted by manufacturing/industrial sites, AFFF release sites, WWTPs, among other pathways.

While PFAS may be found at very low concentrations in soil, surface water or groundwater throughout the State, there are certain areas where one would expect to see higher concentrations. In order to develop a comprehensive "Footprint," MDE must be able to identify sources of PFAS throughout the State, including WWTPs, landfills, AFFF sites, biosolid application sites, industrial sources and more. Once identified, the next step would be to quantify the impacts these sources have on natural resources.

In addition to source identification, source controls must also be considered. MDE must think about how to best manage PFAS releases when a source has been identified.

MDE has already taken strides to better understand PFAS in Maryland. Work that is ongoing or has been previously completed will assist in characterizing Maryland's "PFAS Footprint" include:

- Identification of 2,000 potential sources of PFAS across the State;
- Assessments with DOD and EPA on military bases with fire suppression training sites;
- PWS Study for PFAS in drinking water at over 130 water treatment plants; and
- Integration of PFAS analysis into the fish tissue monitoring program.

Additionally, to broadly develop the State's current "PFAS Footprint," MDE should consider a study to assess the presence of PFAS in WWTPs, biosolid application sites, and landfill leachate.

Investigating the Impacts of Biosolid Application

At the national level, it was estimated in 2001 that over 2,000 kg of PFAS are land applied in biosolids annually[10]. The land application of biosolids is common in Maryland. Some regions and fields within those regions have received much greater quantities of biosolids than other regions. These differences can help assess if land application of biosolids is a mechanism that may (re)introduce PFAS into the food chain.

Therefore, MDE, MDA, and USDA could collaborate to conduct a study on PFAS concentrations in biosolids and seek to better understand whether there are regional differences based on the amount of biosolids applied. It will be important to recognize that biosolids being land applied today may have lower concentrations of PFAS compared to biosolids applied 20 or more years ago.

PFAS and Maryland's Seafood

Recent studies have shown that mollusks, such as oysters, do not appear to bioaccumlate PFAS, however, the biological reasons for this remain unknown. Serum from fish have shown variable concentrations of PFAS from non-detect to elevated levels, but large-scale studies of serum, blood, and fillets of commonly eaten fish have yet to be conducted. To-date there are no known studies of PFAS in crab meat or its carapace (crab shells are either sent to landfills or recycled into products such as fertilizers).

Maryland is also in a very unique geographic position to study PFAS bioaccumulation in aquatic organisms in fresh, estuarine, and salt water. MDE, the Maryland Department of Natural Resources

(DNR), the United States Geological Survey (USGS), the Maryland Department of Health (MDH), and academic researchers should consider collaborating to study PFAS concentrations in fish and crabs along the fresh to saltwater gradient. However, since the methodology of such a study has not been standardized there may be a need to undertake additional basic research before necessary monitoring systems and conclusions can be drawn.

Hydrological Understanding
Since concentrated sources of PFAS in soil can be considered a "point source" for releases into groundwater, it is important to understand the hydrologic conditions of the receiving waters. If PFAS enters the groundwater systems, understanding the flowpath is important in assessing potential risks. In some areas of the State, such as the Eastern Shore, groundwater can move very slowly. Groundwater that is more than 20 years old may have higher concentrations of PFAS since that was during a period of time when they were manufactured in the U.S. (although there are no known manufacturing sites within the State).

In some parts of the State, relatively shallow aquifers are used for drinking water and agricultural irrigation systems. The time it takes for PFAS to get into shallow aquifers may be considerably less than deeper groundwater.

MDE, the Maryland Geological Survey (MGS), the Maryland Department of Agriculture (MDA), and the USGS should consider working collaboratively to better understand the concentration of PFAS in groundwater in various areas of the State and the potential threats it may pose. These studies should initially be focused in regions that have known or expected elevated PFAS levels.

Human Biomonitoring and Exposure Characterization
Nationally, there has been some work done to correlate biomonitoring of PFAS levels in blood with reported health effects and reported information on exposure, including through the diet. These studies can provide useful information, particularly in populations that are considered most at risk, either because of their profession or their exposure potential to known sources.

MDH, CDC, and academic epidemiologists should consider working collaboratively to determine the relationship between exposure to PFAS and health outcomes in Marylanders. This work may be helpful to MDE in setting exposure limits and making recommendations to reduce exposures (such as Fish Consumption Advisories). MDE should consider placing emphasis on certain communities, which may experience higher exposures to PFAS due to increased reliance on subsistence fishing. These types of studies require careful considerations and clear communications to the study participants.

CONCLUSIONS
There is still much to be learned regarding the risks posed to human health by PFAS, the sources of PFAS, how PFAS behave in the environment and how to effectively address PFAS sources and releases. MDE looks forward to working collaboratively with its multiple partners to garner a better understanding of PFAS sources and risks as well as how to best remediate impacted areas with the goal of reducing risks to Maryland's citizens. These studies will need to be carefully designed and will require

funding, enhanced expertise, and strategic partnerships within and beyond the State to complete. Based on the reaction of the assembled participants, however, Maryland is on the correct path toward a greater understanding of the risks of PFAS from multiple sources to her citizens and environment.

SOURCES CITED

1 - epa.gov/pfas/basic-information-pfas
2 - pfas-1.itrcweb.org/2-pfas-chemistry-and-naming-conventions-history-and-use-of-pfas-and-sources-of-pfas-releases-to-the-environment-overview/
3 - pfas-dev.itrcweb.org/wp-content/uploads/2020/10/history_and_use_508_2020Aug_Final.pdf
4 - pfas-1.itrcweb.org/5-environmental-fate-and-transport-processes/
5 - atsdr.cdc.gov/pfas/health-effects/index.html
6 - mde.maryland.gov/programs/Water/water_supply/Documents/PFAS-MDE_memo_to_CommunityAndNCNT_PWS2019-12-18_final.pdf
7 - epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf
8 - epa.gov/sites/production/files/2020-01/documents/pfas_action_plan_feb2020.pdf
9 - michigan.gov/pfasresponse/0,9038,7-365-88059_91299---,00.html
10 - Venkatesan, A. K.; Halden, R. U. (2013). National inventory of perfluoroalkyl substances in archived U.S. biosolids from the 2001 EPA National Sewage Sludge Survey. *Journal of Hazardous Materials* 252-253, 413-418.

Appendix 1 – SCIENTIFIC ROUNDTABLE PARTICIPANTS

Charge to the Participants
The Honorable Ben Grumbles, Secretary, Maryland Department of the Environment
Dr. Peter Goodwin, President, University of Maryland Center for Environmental Science

Co-Conveners
Denise Keehner, MDE
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Kevin Sowers, Institute of Marine and Environmental Technology, UMBC
Rebecca Warns, MDE

Staff
Emily Ramirez, UMCES

NOTE: This summary is a product of UMCES and MDE based on the presentations and comments from all the participants.

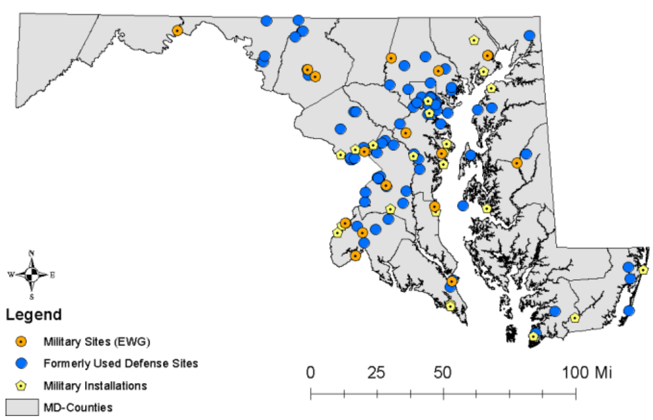
Appendix 2 – PFAS AND MILITARY INSTALLATIONS IN MARYLAND

In addition to the results from the 2018 DOD report, additional investigations are underway at the following list of military installations. Investigation status (i.e.,preliminary assessment, site investigation, remedial investigation) and investigative media (i.e.,groundwater, soils, surface water, etc.) vary base to base. For installation-specific information, please contact Ira May (ira.may@maryland.gov) Chief, Federal Assessment and Remediation Division, MDE- Land and Materials Administration.

- Navy Facilities
    - Naval Research Laboratory, Chesapeake Bay Detachment, Chesapeake Beach
    - Bay Head Road Annex, Annapolis
    - Former Naval Research Laboratory, White Oak
    - Naval Support Activity Annapolis (NSAA)
    - David Taylor Research Center, Annapolis
    - David Taylor Research Center, Carderock
    - NSF Indian Head, Indian Head
    - NAS Patuxent River, St Mary's County
    - NAS Patuxent River, Webster Annex, St Mary's County
    - Naval Recreation Center, Solomon's, Calvert County
- Army Facilities
    - Aberdeen Proving Ground, Aberdeen and Edgewood
    - Forest Glen Annex, Silver Spring
    - Fort Detrick, Frederick
    - Fort Meade BRAC (the former and closed sections of the base), Odenton
    - Fort Meade (the present base) Odenton
- Air Force Facilities
    - Air Force Reserve, Martin State Airport, Middle River
    - Joint Base Andrews, Camp Springs
    - Brandywine DRMO, Brandywine

Appendix 3- UPDATE OF PFAS ASSESSMENT PLAN ON MILITARY BASES

Military Locations Considered Potential Sources of Contamination



MDE continues to work with the DOD and EPA to assess, remediate and monitor DOD sites in Maryland where PFAS are present.

DOD monitored military facilities throughout the country and in 2018 released a report on its investigation of PFAS at military bases. This report identified four sites in Maryland with PFAS contamination in groundwater. Those sites are: the former Fort Meade Tipton Airfield; Naval Research Lab Chesapeake Beach Detachment; the former Navy Bayhead Annex in Annapolis; and the former Naval Research Laboratory in White Oak.

Since that time, PFAS compounds have been identified at four additional military installations in Maryland. Those sites are: Aberdeen Proving Ground; Naval Air Station Patuxent River; Joint Base Andrews; and the former Brandywine Defense Reutilization and Marketing Office. Preliminary assessments are being conducted at the rest of the military facilities in Maryland, including Fort Detrick, Forest Glen Annex, and Naval Air Station Patuxent River's Webster Field Annex.

Initial efforts were focused on determining whether any off-site properties are affected by PFAS. Three domestic wells at the Chesapeake Bay Detachment site had detections but they were far below the EPA's Health Advisory level. As additional testing proceeds there may be other DOD installations in Maryland where PFAS compounds are found in the groundwater.

On March 3, 2020, the U.S. Navy sponsored a public information meeting for residents in the vicinity of Naval Air Station Patuxent River to learn about the Navy's next stage of its assessment program to determine the occurrence of certain PFAS on the Navy installations that have known or potential releases of these compounds into the environment. Concerns were raised at this public meeting about potential exposures to these compounds associated with the use of PFAS-containing materials at the base's Webster Field Annex. As a result of the concerns expressed at this public meeting, and in furtherance of MDE's mission to protect and restore the environment for the health well-being of all Marylanders, MDE initiated a pilot study to assess whether surface water and potentially oysters in the vicinity of Webster Field Annex have elevated levels of PFAS. Results from this pilot study can be found here (link).

A summary of the actions at each of the bases in Maryland to date, as of July 2020, is as follows:

Navy Facilities

Naval Research Laboratory, Chesapeake Bay Detachment, Chesapeake Beach. The Navy Research and Development (R&D) community has conducted testing of aqueous film-forming foam (AFFF) products for the U.S. Navy from 1968 to the present. The base drinking water supply well, approximately 500 feet deep, was sampled for PFOA and PFOS in September 2016, and neither of those compounds were detected.

The Navy conducted a Site Inspection (SI) in 2017, which included installation and sampling of deep and shallow groundwater monitoring wells on the base and near base boundaries to determine the likelihood of off-site migration and impact to private drinking water wells. Sample analysis included three compounds: PFOS, PFOA, and PFBS. The SI confirmed the point of release to be the fire-testing pad area. A large associated plume of contamination in the shallow aquifer extends over much of the facility, with the highest concentration at the fire-testing pad (234,000 ppt PFOS).

As a result of this detection of PFAS in the shallow groundwater aquifer, the Navy began notifying the public in areas potentially impacted by groundwater contaminants. Although a 150-foot-thick clay formation separates the shallow aquifer from the deeper aquifer tapped by area private drinking water wells, the Navy nevertheless planned off-site private well sampling to ensure there were no site contaminants affecting private drinking water wells. Sampling of approximately 80 private wells off-base took place in July 2018 for 14 PFAS compounds, mainly to the northeast and southeast of the site, based on known groundwater flow direction. Although there were detections at three locations, none approached the EPA’s PFAS HA of 70 ppt. A public meeting occurred prior to and after the sampling, first to inform the public and obtain permission for sampling, and then to explain sampling results and further planned activities on-site.

Currently the plan moving forward is to conduct an Expanded Site Investigation (ESI) of the Fire Training Area (Site 10), with groundwater and surface water sampling. A second Restoration Advisory Board (RAB) meeting is planned in the near future.

Bay Head Road Annex, Annapolis is a former facility used by the Navy R&D community. The Remedial Investigation (RI) is presently being finalized. AFFF was used for fire training on a concrete burn pad. PFOS/PFOA contamination of surface/subsurface soil, surficial aquifer groundwater, and sediment/surface water downgradient of the former installation have been documented. There is no drinking water exposure to area residents, who are served by municipal water.

Former Naval Research Laboratory, White Oak. AFFF was used at a few locations at the site, including Site 7 and Site 5 at burn pits. A preliminary Assessment (PA) has been completed and some soil and groundwater (gw) sampling has been completed. Concentrations have been detected near the HA. All area residents are on municipal water.

Naval Support Activity Annapolis (NSAA). A Preliminary Assessment/ Site Investigation (PA/SI) has been completed and MDE is awaiting the document for review. Very minor concentrations of some PFAS have been detected in some wells at Site 1 and 2, including the background well for these sites.

David Taylor Research Center, Annapolis. This site is a former R&D facility adjacent to NSAA's Site 1 and 2. Groundwater sampling was done, and very low concentrations of PFAS were detected in some wells.

David Taylor Research Center, Carderock. A PA is to be accomplished this year.

NSF Indian Head, Indian Head. A PA is currently underway. There are a total of five sites that have the potential to be contaminated with PFAS (three on the main facility and two on the Stump Neck Annex). The estimated completion date for the PA is January 2021. It is anticipated that the fieldwork for the forthcoming SI will conclude in August 2021.

NAS Patuxent River, St Mary's County. The PFAS SI work plan was approved by MDE's Land Restoration Program (LRP) in June 2020. Sampling of groundwater and soil at sites where previous releases of AFFF were documented is scheduled to begin in early July 2020. The PA identified 16 sites where AFFF releases were either documented or likely. Per the SI work plan soil and groundwater samples will be collected from these 16 sites. Six in-use potable drinking water wells at the base were sampled for PFAS constituents between December 2014 and June 2015, and the results were non-detect for PFAS constituents. PFAS were detected in soil and shallow groundwater samples collected from Site 34, which was a drum disposal site historically. The maximum concentration of PFOS/PFOA in shallow groundwater at Site 34 was 1,137 parts per trillion (ppt).

NAS Patuxent River, Webster Annex, St Mary's County. The PFAS SI Work Plan was approved by MDE's LRP in June 2020. Sampling of groundwater and soil at two sites where previous releases of AFFF were documented is scheduled to begin in early July 2020. The two sites identified in the PA where AFFF was used were the AFFF Crash Truck Maintenance Test Area and Fire Station 3. Two in-use potable drinking water wells at the base were sampled for PFAS constituents in October 2016 and the results were non-detect.

Army Facilities

Aberdeen Proving Ground, Aberdeen and Edgewood. A PA has been completed, and a SI is to be begun this year. MDE is expecting a SI work plan for review in July 2020. Numerous sites around the facility have been identified as sites where AFFF foam was used or releases occurred. The Harford County Perryman Well Field has been impacted by a groundwater plume at the Western Boundary Study Area of the Aberdeen Area above EPA HA and is treated with GAC filtration and monthly testing of treated water. The Perryman well water is blended post-treatment with surface water from (primarily) the Loch Raven Reservoir and occasionally from the Susquehanna River before delivery to the public. It is expected that there will be several additional sites that will have full scale investigations in the near future.

Forest Glen Annex, Silver Spring. A PA is being conducted presently. There is only one confirmed usage of PFAS at the facility at the fire station between 2008 and 2018. Soil sampling will be conducted in the near future.

Fort Detrick, Frederick is finalizing the work plan for PFAS sampling. Groundwater near the landfill was sampled for PFAS in advance of the PA/SI sampling in order to aid in the design of the treatment system for the pump and treat pilot study. This pump and treat study is being done to determine the ability to remediate the Trichloroethylene groundwater plume at Area B. During this sampling, low levels were detected in groundwater near the landfills on Area B (<20 ppt).

Fort Meade BRAC (the former and closed sections of the base), Odenton. The groundwater near Tipton Airfield was sampled in 2016. The highest detection near Tipton Airfield was 89,000 ng/L PFOS. Follow-on work in 2018 indicated that the PFAS was not migrating off-site, and not impacting water supplies for buildings on the Patuxent Wildlife Refuge. Additional PFAS sampling will be conducted in support of the upcoming Five Year Review.

Fort Meade (the present base) Odenton. A PA is underway. MDE expects that there will be additional sampling performed at areas associated with past and current fire department buildings and training areas. MDE waiting for a work plan for this sampling.

Air Force Facilities

Air Force Reserve, Martin State Airport, Middle River. A PA/SI was completed in 2019. The PA identified 13 locations where releases of AFFF might have occurred, including fire training areas, former and current fire stations, hangars, hazardous waste storage facilities, fire fighting equipment testing areas, and storm water outfalls with potential connectivity to areas of known or possible releases. Eleven of the 13 locations were recommended for further sampling. Eleven temporary wells were put in and nine of them showed concentrations above the EPA HA with concentrations for PFOS ranging from 0.0712 µg/L to 13.7 µg/L. Concentrations of PFOA ranged from 0.0929 µg/L to 1.66 µg/L. Concentrations of PFOA and PFAS combined ranged from 0.07849 µg/L to 14.5 µg/L. A RI will be conducted in the future. Groundwater flows directly into the Chesapeake Bay. While there is no possibility of drinking water impacts, releases to the Bay could result in elevated PFAS concentrations in aquatic species.

Joint Base Andrews, Camp Springs. The 2015 PA identified 10 AFFF areas requiring additional investigation. During the 2018 SI process, that number of sites was adjusted to nine, most of which are hangars and fire-training areas. The SI tested surface soil (up to 17,000 µg/kg PFOS; up to 150 µg/kg PFOA), subsurface soil (up to 210 ug/kg PFOS; up to 5.9 µg/kg PFOA), groundwater (up to 38,400 ng/L PFOS/PFOA), surface water (up to 8,510 ng/L PFOS/PFOA) and SED (up to 27 µg/kg PFOS; up to 0.61 µg/kg PFOA) for PFBS, PFOA, and PFOS.

Brandywine DRMO, Brandywine. A PA/SI was conducted in connection with the Joint Base Andrews effort. PFAS was found at one site due to improper storage of AFFF. The small groundwater plume will be investigated in the future, along with Joint Base Andrews.

Report Links

DOD PFAS 101:
media.defense.gov/2020/Feb/06/2002245003/-1/-1/1/PFAS-101-V2.PDF

DOD Spotlight on PFAS:
defense.gov/Explore/Spotlight/pfas/

DOD 2018 PFOS and PFOA report:
partner-mco-archive.s3.amazonaws.com/client_files/1524589484.pdf

DOD 2020 PFAS Progress Report:
https://media.defense.gov/2020/Mar/13/2002264440/-1/-1/1/PFAS_Task_Force_Progress_Report_March_2020.pdf

Department of the Navy PFAS Management Strategy:
secnav.navy.mil/eie/pages/pfc-pfas.aspx

March 3, 2020 NAS Patuxent River Restoration Advisory Board (RAB) PFAS Public Meeting Posters and Fact Sheets:

Public Meeting Posters:
https://www.navfac.navy.mil/content/dam/navfac/Environmental/PDFs/env_restoratio n/nas_patuxent_river/NAS_Patuxent_River_Posters_PFAS_Mar2020.pdf

NAS Patuxent River PFAS Fact Sheet:
https://www.navfac.navy.mil/content/dam/navfac/Environmental/PDFs/env_restoration/nas_patuxent_river/NAS_Patuxent_River_Fact_Sheet_PFAS_Jan2020.pdf

EPA PFAS Fact Sheet:
https://www.navfac.navy.mil/content/dam/navfac/Environmental/PDFs/env_restoration/nas_patuxent_river/EPA_Fact_Sheet_PFAS.pdf

Appendix 4 - EPA Research Deliverables between 2020-2022

Since publishing their PFAS Action Plan in 2019, the EPA has taken key steps to better understanding PFAS science as it relates to toxicity, treatment, site remediation, disposal, and more. The following research deliverables are anticipated to be published in the next few years.

- Deliverables for 2020
  - Analytical Method for Air Emission Sampling and Analysis and Total Organic Fluorine
  - Public Repository for Toxicity/ Toxicokinetic Data
  - Case Study: PFAS Fate and Transport (Air Deposition)
  - Final Toxicity Assessments for PFBS/ GenX
  - Draft IRIS Assessment for PFBA
  - Report on Bioactivity of ~120 PFAS
  - Updated Drinking Water Treatment Performance, Cost Models and Data
  - Next Update to Treatability Database
  - Groundwater Remediation Performance, Cost Models and Data
  - Toolbox of knowledge on current and innovative solutions/ methods for the destruction of PFAS
- Deliverables for 2021
  - Isotope Dilution Method for Surface Water, Groundwater, Soils, Sediment, Biosolids
  - Framework for Comparative PFAS Exposure Analysis
  - Multimedia Human Exposure Assessments for 6 PFAS
  - Draft IRIS Assessment for PFHxA, PFHxS, PFDA, PFNA
  - Review/ Synthesis of Bioaccumulation Literature
  - Update bioaccumulation factors for PFAS in aquatic species
  - Report on Fate of Reactivated GAC and IX Filters
  - Review of Thermal Treatment of PFAS-contaminated Soils
  - Fate and Transport of PFAS from Land Application of Biosolids
  - Migration potential of PFAS via Vapor Intrusion
  - PFAS Behavior in Incineration Environments
  - Thermal Treatment of PFAS-Containing Biosolids
- Ongoing PFAS Research Efforts
  - Updates to Treatability Database
  - Updates to ECOTOX Database
  - Models to Predict Chemical/ Physical Properties