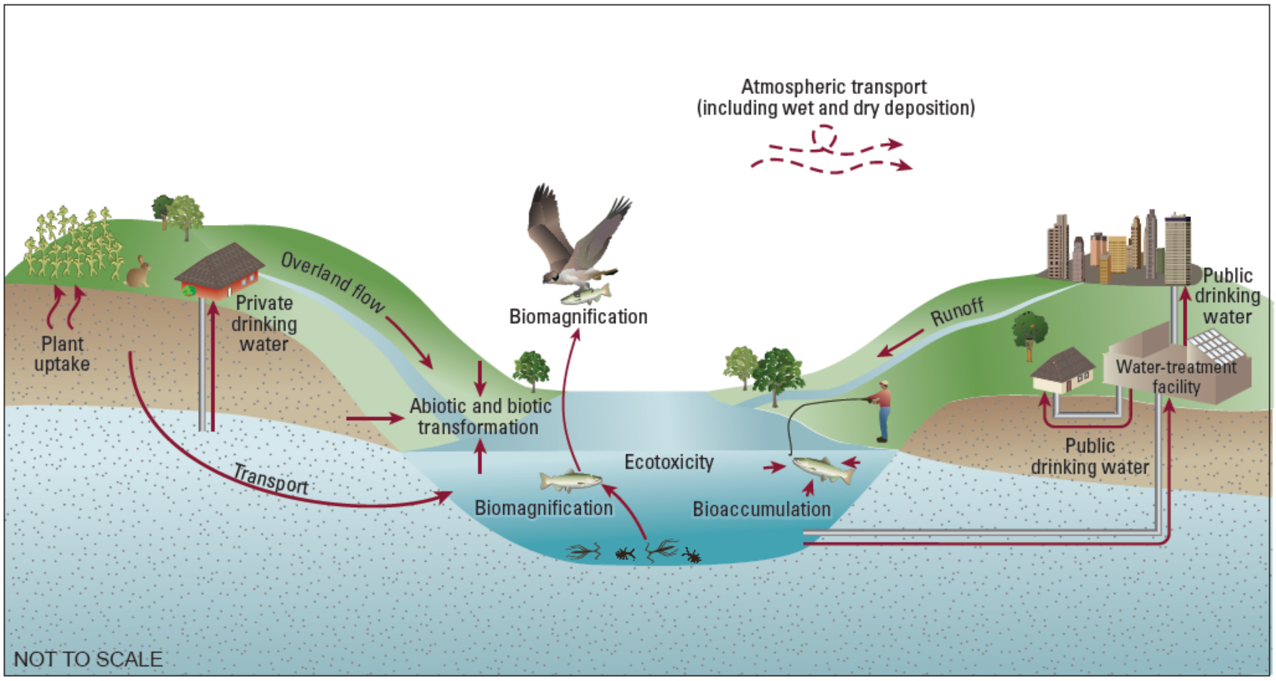
Improving Understanding and Coordination of Science Activities for Per- and Polyfluoroalkyl Substances (PFAS) in the Chesapeake Bay Watershed



STAC Workshop Report
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STAC Publication 2023

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at http://www.chesapeake.org/stac.

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Cover graphic from: Conceptual diagram showing the major mechanisms of the fate, transport, and exposure pathways of perfluoroalkyl and polyfluoroalkyl substances (PFAS) in the environment from Tokranov et al. (2022).

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Executive Summary

Per- and polyfluoroalkyl substances (PFAS) have been manufactured and used in a variety of industries in the United States since the 1940s. PFAS are ubiquitous and persistent in the environment and have the potential to have adverse human and ecological health effects. There are more than 12,000 unique compounds, making analysis and reporting difficult. A STAC workshop gathered speakers from Chesapeake Bay jurisdictions, federal agencies, and academic institutions, including representatives from across the Nation, to better understand the state of the science, improve science coordination, and propose approaches to improve our knowledge of PFAS. The workshop was designed to (1) summarize current understanding of sources, occurrence, and fate of PFAS, (2) identify current efforts and approaches to inform the potential effects on fish and wildlife, and their consumption by humans, (3) consider study designs, and comparable sampling and analysis methods, for a more coordinated PFAS science effort, (4) determine and prioritize knowledge gaps, and (5) provide actionable scientific recommendations for monitoring and research.

This workshop report summarizes the current understanding of sources, occurrence, and fate of PFAS and identifies on-going efforts and approaches to inform the potential effects on fish and wildlife, and their consumption by humans. The report provides overarching guidance for research and monitoring to address science gaps, foster communication and collaboration, to help stakeholders better coordinate PFAS efforts to ensure data comparability across the entire Chesapeake Bay Watershed. Enhanced coordination among jurisdictions and agencies requires the creation of common study objectives to collect data and information based upon the media being sampled. This strategy could ensure the ability to conduct statistical analysis with "large" pooled data, allowing for a better understanding of PFAS occurrence, fate, transport, and source apportionment within the Bay and across the watershed. With the release of EPA Strategic Roadmap in 2021, the PFAS landscape is rapidly evolving. After the conclusion of the workshop, the EPA released an updated draft Method 1633 for approval and updated interim health advisories (HA's) for perfluorooctanoate (PFOA), perfluorooctane sulfonate (PFOS), perfluorobutane (PFBS) and hexafluoropropylene oxide (HFPO) dimer acid and its ammonium salt (Gen X). Similarly, all guidance and science gaps identified in this report are rapidly evolving and should be reassessed periodically.

Ten science gaps were identified by workshop participants with six overarching actionable recommendations supporting at least one of the science gaps. The science gaps were ranked by need and binned into four categories designed to address data needs on 1) sources, fate, and occurrence more broadly across the watershed, 2) exposure and bioaccumulation across a range of species, 3) fish consumption advisories, and 4) ecological effects across a range of species, PFAS compounds and concentrations. The 10 science gaps identified by the workshop participants are organized by priority need and listed below:

Urgent, short-term

- Temporal and spatial assessment of PFAS occurrence in tributaries with an emphasis on identifying loads from both point and nonpoint sources.
- Coupled fish and surface water samples to develop species-specific bioaccumulation factors including more regional studies to related surface water and tissue PFAS concentrations across a range of species using standardized methods.

Near-term

- Development of a regionally uniform bioconcentration factor approach to drive fish consumption advisories.
- Information on effects of PFAS on different life stages of fisheries in estuarine and freshwater systems.

Near-to-mid-term

- Studies directly designed to address food chain/ biomagnification of PFAS.
- Studies addressing the biological effects of PFAS at lower concentrations.
- Better understanding of what land uses are most likely to contribute to PFAS detections and whether that information can be used to predict occurrence, delivery, and load.

Long-term

- Cumulative effects of PFAS, other contaminants and biological stressors on aquatic species.
- Studies specifically designed to provide information on chronic, long-term toxicity for larval oysters and blue crabs.
- Prioritize studies directly assessing the interface between the aquatic and terrestrial environments (e.g., ducks and other avian species).

A list of six actionable recommendations was identified by the workshop participants, each recommendation was organized by the science gap or gaps they filled and were subsequently binned by the steering committee into three overarching themes:

Theme 1: Communicate and collaborate

- Enhance interaction between management agencies and scientists to facilitate broad coordination across the Chesapeake Bay Watershed,
- Develop data needs for fish consumption advisories collaboratively across jurisdictions,

Theme 2: Study design and approaches

- Design a PFAS monitoring network within the Chesapeake Bay Watershed,
- Prioritize studies designed to address PFAS occurrence and effects in different land-use settings,

Theme 3: Consistency in data collection

- Standardize field collection and analytical approaches to better compare data among studies and jurisdictions,
- Collect standardized data to develop ecological risk assessments across a range of species for the protection of aquatic resources.

Many of the science gaps identified above, though at times related, do not need to be pursued sequentially to successfully advance our understanding of PFAS in the Chesapeake Bay and its watershed. The scientific and resulting policy landscape for PFAS is rapidly evolving. The current, numerous scientific gaps, common to many jurisdictions across the Chesapeake Bay Watershed, represent a unique opportunity to pool resources, streamline methods and approaches, and share findings. An integrated and timely response to the six actionable recommendations outlined in this workshop report, particularly the ten identified science gaps, could benefit both current needs as well as future assessments at broader scales.

Introduction

Per- and polyfluoroalkyl substances (PFAS) have been manufactured and used in a variety of industries in the United States since the 1940s. They consist of more than 12,000 unique compounds and have been used as firefighting chemicals, in consumer products such as water-repellent fabrics, food packaging, and nonstick cookware, and in industrial activities (Sunderland et al., 2019; Glüge et al., 2020; Interstate Technology & Regulatory Council, 2022). These compounds are persistent in the environment and have been shown to have adverse human and ecological health effects (Sunderland et al., 2019; Evich et al., 2022; Tokranov et al., 2022). Point and nonpoint sources of PFAS to the environment are diverse and include biosolids application, outdoor products (e.g., ski waxes), industrial releases, firefighting foams, and discharges from wastewater treatment, septic, stormwater, and landfill systems (Houtz et al., 2013; Masoner et al., 2019; Masoner et al., 2020; Lenke, et al., 2021; Kurwadkar et al., 2022; Salvatore et al., 2022; Sims et al., 2022; Thompson et al., 2022). Individual compounds can be referred to as either long chain, legacy compounds that have greater than six carbons (e.g., perfluorooctanoate (PFOA), perfluorooctane sulfonate (PFOS)) or short chain compounds that have less than six carbons (e.g., perfluorobutane sulfonate (PFBS)). Shorter chain PFAS, which have been introduced as alternatives to their longer chain counterparts, are widely detected in the environment and can be more mobile than long-chain PFAS (Li et al., 2020). In 2016, the U.S. Environmental Protection Agency (EPA) introduced a non-enforceable lifetime-human health advisory in drinking water of 70 ng/L for combined concentrations of PFOS and PFOA (EPA, 2016), and many states have since enacted their own drinking water standards (Interstate Technology & Regulatory Council, 2022). In October 2021, EPA released its PFAS Strategic Roadmap designed to consider the entire lifecycle of PFAS from their unique properties, the ubiquity of their use in everyday products, and the multiple pathways of exposure (EPA, 2021). Since the release of the roadmap, EPA has been developing interim health advisories for drinking water and aquatic life criteria for freshwater species. In April 2022 (prior to the workshop) EPA released a draft aquatic life ambient water quality criterion for PFOA (6,100 ng/g wet weight in whole fish) and PFOS (6,175 ng/g wet weight in whole fish; EPA, 2022) and in June 2022 EPA released its interim drinking water health advisories for PFOS (0.02 ng/L), PFOA (0.004 ng/L), PFBS (2,000 ng/L) and Gen X chemicals (10 ng/L; EPA, 2022). Comprehensive strategies are needed to protect public health and ecosystems by researching, restricting, and remediating PFAS contamination. While jurisdictions have begun some studies on PFAS in drinking water (for information see PA DEP, 2022; MDE, 2022; VA DEQ, 2022; WV DEP, 2022), little is known about PFAS in the Chesapeake Bay ecosystem. There is the possibility for widespread occurrence, as well as biomagnification through the food web and subsequent risk to fish, wildlife, and human health. There is an urgent need for better standardized and unified approaches for data collection/analysis and for sharing of knowledge and close cooperation among and between the various research institutions and management agencies of the Chesapeake Bay Watershed.

The Chesapeake Bay Program (CBP) Scientific and Technical Advisory Committee (STAC) held a workshop on May 17-18, 2022. The purpose of this workshop was to better understand the state of the science, improve science coordination and propose approaches to improve our knowledge of PFAS. The information was used to prioritize questions about potential effects on aquatic resources that could be addressed within the Chesapeake Bay

Watershed. The workshop gathered state, federal, academic, and industry partners to better understand the state of the science and improve science coordination specifically related to PFAS.

The specific objectives of the workshop were as follows:

- Summarize current understanding of sources, occurrence, and fate of PFAS,
- Identify current efforts and approaches to inform the potential effects on fish and wildlife, and their consumption by humans,
- Consider study designs, and comparable sampling and analysis methods, for a more coordinated PFAS science effort,
- Identify key research needs/data gaps and actionable recommendations associated with better understanding potential effects on fish, wildlife, and their consumption as an impact on human health.

Presenters from the Chesapeake Bay Watershed and other regions across the Nation spoke on topics related to ongoing efforts on the occurrence, fate, and transport of PFAS, considerations for establishing PFAS thresholds and development of consumption advisories, the ecological effects of PFAS, and considerations for coordinated monitoring and research efforts for PFAS. The participants were asked to identify knowledge gaps related to each topic. Workshop participants were tasked with developing actionable recommendations for more coordinated monitoring and research of PFAS to address priority science gaps identified for the objectives described above, including an integrated and cost-effective approach for monitoring, modeling, and innovative research across the watershed.

State of the Science: PFAS in the Chesapeake Bay Watershed and other Landscapes

The state of the science was assembled by gathering information about ongoing efforts to address PFAS in the Chesapeake Bay Watershed and inviting speakers from other places around the Nation to share their current findings and efforts. Additionally, there was an opening talk summarizing a review article from a national PFAS workshop. ***It is important to note that this workshop was conducted prior to the release of EPA's new interim health advisories (HAs) released in June 2022 (EPA, 2022a). All reference doses for consumption advisories are based on previous HAs for PFOS and PFOA released by EPA in 2009 (EPA, 2009).***

Current understanding of the ecological effects of PFAS

PFAS are a class of chemicals with over 12,000 different compounds having a wide range of physical and chemical properties (Smith et al., 2016). The toxicity of these compounds is relatively unknown because most studies have focused on a relatively small number of chemicals, such as PFOA and PFOS (Conder, 2020). Jeff Steevens from the U.S. Geological Survey (USGS) opened the workshop by providing a brief overview on the ecotoxicology and bioaccumulation of PFAS that was recently summarized in a review article following a workshop of the Society of Environmental Toxicology and Chemistry (Ankley et al., 2021). Databases, such as the EPA ECOTOX Knowledgebase, have summarized toxicity data for PFAS across a range of aquatic and terrestrial taxa (EPA, 2022a). In the most recent update, the ECOTOX Knowledgebase summarized data for 600 species and 159 different PFAS (Gary Ankley, U.S. Environmental Protection Agency, oral communication, 2022). These data primarily include aquatic organisms with limited data for amphibians, birds, reptiles, and mammalian wildlife and little to no toxicity data for most invertebrate taxa and plants. Most studies describe acute exposures and effects with very few reporting chronic exposures and sublethal effects. In general, most studies are limited to controlled laboratory experiments. Therefore, there is a need for field studies that have documented effects following long-term exposures to sublethal concentrations. Furthermore, there is a need for studies that examine the effects of PFAS mixtures (McCarthy et al., 2021).

There are a wide range of regulatory activities focused on criteria development or establishing risk-based screening approaches for PFAS. A summary of these criteria is maintained by the Interstate Technology and Regulatory Council (Interstate Technology & Regulatory Council, 2022). Most of the PFAS criteria have been developed for PFOA and PFOS for application to aquatic life or drinking water. Recently the EPA released draft aquatic life criteria for PFOA and PFOS (EPA, 2022b). There are numerous knowledge gaps in the fate and toxicity of PFAS (Tokranov et al., 2021). Future research may include adapting existing tools to understand PFAS toxicity where little or no data exist.

Ongoing efforts to address PFAS in the Chesapeake Bay Watershed

A summary of ongoing efforts in the Chesapeake Bay watershed was compiled prior to the workshop. Notable findings are summarized below:

- PFAS programs in jurisdictions are currently focused on point sources, particularly sources near industrial sites and military or civilian fire training areas.
- Human health is the primary driver for studies by jurisdictions, leading to a focus on defining occurrence of PFAS in surface water and groundwater sources of drinking water, public water supplies, and fish.
- Limited information is currently available on the ecological effects of PFAS, and these studies are primarily carried out by federal and academic researchers.

Michelle Lorah (USGS) provided a summary of the ongoing efforts designed to understand the sources, occurrence, fate, and effects of PFAS in the Chesapeake Bay watershed. This information was compiled by the PFAS steering committee prior to the workshop using information from (1) responses to STAC inventory questions distributed prior to the workshop to regulators and researchers at federal and jurisdiction agencies, an interstate commission, non-government organizations (NGOs), and academic institutions in the Chesapeake Bay Watershed; (2) public sources available on web pages; and (3) a literature review completed in spring 2022 of relevant published research (see Appendix C). All information provided in this section is based on responses compiled from the STAC inventory questions. An overview (Appendix C) was organized for the workshop around the following inventory questions:

Have potential sources been summarized or categorized in your jurisdiction (fire training facilities, wastewater treatment plants (WWTP), industries, biosolids, etc.)?

State agencies described a process of initial desktop evaluation of potential sources to prioritize sampling for public water supplies (i.e., groundwater, surface water), followed by targeted sampling in potential hotspots or vulnerable areas, and then refining or expanding source evaluation and monitoring. PFAS programs in jurisdictions who responded to the inventory are currently focused on point sources, particularly sources near industrial sites and military or civilian fire training areas. Only researchers at federal and academic institutions reported current studies related to nonpoint PFAS sources (e.g., biosolids land application, stormwater runoff), and no studies of septic systems or atmospheric deposition of PFAS were reported or found in the literature in the Chesapeake Bay area (Figure 1).

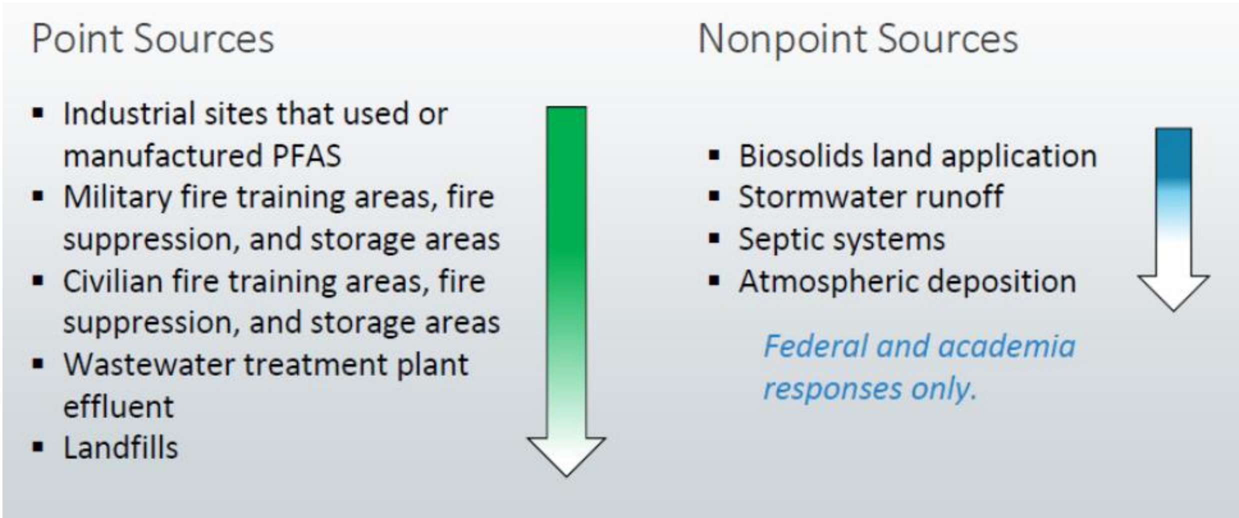

Figure 1: Schematic of potential PFAS sources that are priorities for current studies reported in inventory responses. Darker colors in arrows indicate the highest number of studies.

What are the goals of any ongoing or planned PFAS studies in the next 1-2 years?

Human health is the primary driver for studies by jurisdictions, leading to a focus on defining PFAS occurrence in surface water and groundwater sources of drinking water, public water supplies, and fish. Goals of current and planned PFAS studies by federal and academic researchers span across categories of defining occurrence, fate and transport, toxicity, and development of new treatment processes.

Are there current PFAS recommended action levels (health/consumption advisories) in your jurisdiction, or work underway to establish?

When the inventory was compiled and the workshop was conveyed, most jurisdictions used the 2016 EPA health advisory levels for combined PFOA and PFOS concentrations (70 ng/L) for drinking water (EPA, 2009), although New York and Pennsylvania have established lower individual criteria for PFOA and PFOS (Interstate Technology Regulatory Council, 2022). Virginia also has established risk-based screening values for PFOS, PFOA, perfluorobutanoate (PFBS), and Gex X. Maryland established risk-based levels for PFOA and PFOS for fish consumption advisories for a Potomac River tributary. Delaware and West Virginia reported use of the 2016 EPA health advisory levels for combined PFOA and PFOS as action levels, and Washington, D.C., did not report any action levels at this time.

Have any studies indicated ecological effects from PFAS?

Because human health concerns are the current driver for PFAS programs reported by jurisdictions, only federal and academic researchers reported studies focused on the potential ecological effects of PFAS. One current academic study is modeling biomagnified concentrations of PFOS spatially for a range of species throughout the Chesapeake Bay Watershed. The need to consider transformation of precursor compounds was also noted to avoid underestimating PFAS bioaccumulation and risks. Other studies have included PFAS analyses of fish, shellfish, or turtles from the Chesapeake Bay or tributaries. A study of potential adverse effects on aquatic organisms from wastewater treatment plant effluent highlights aggregated effects of chemical mixtures, including PFAS (Barber et al., 2022). Limited information is available on PFAS in tidal areas, but a recent study compared PFAS in seawater and plankton in coastal areas to sites located offshore along the continental shelf. The study author reported the highest PFOS and PFOA concentrations in samples from the mouth of the Chesapeake and Delaware Bays adjacent to urban centers compared to offshore site and showed a strong inverse relationship with salinity reflecting enrichment from riverine inputs (Zhang et al., 2019).

What types of PFAS studies would you like to initiate in the next 3-5 years?

The types of PFAS studies planned in the next 3-5 years were similar to those reported for current (1-2 year) studies, although there was an increase in planned fate and transport studies (Figure 2). Most of the focus over the next 5 years especially at the jurisdictional level is related to occurrence studies with an emphasis on drinking water sources and other surface waters.

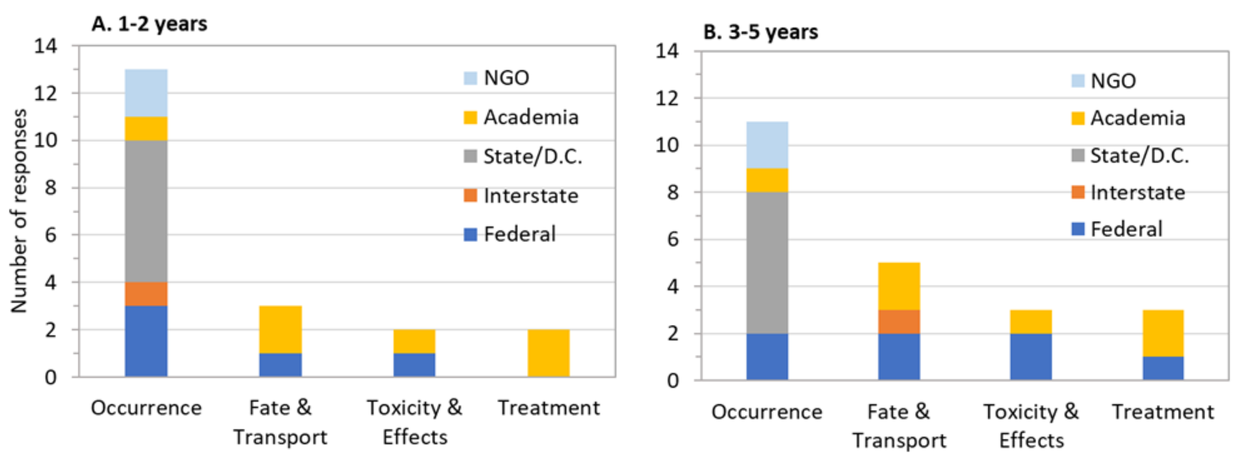

Figure 2: Program foci reported in inventory responses for (A) current (1 – 2 years) and (B) planned (next 3– 5 years) PFAS studies. The total number of inventory responses was 18, but some responses included more than one category. NGO; non-government organization

Quantifying the risk: Examples of what investigations in other watersheds have discovered about PFAS and its ecological burden on fish and wildlife

Three panelists were invited from other large landscapes, including the Great Lakes, the Delaware River Watershed, and the Puget Sound. A summary of notable findings provided by the panelists include:

- In the Great Lakes studies, whole fish were assessed with isotope dilution analysis for sixteen long- and short-chain PFAS in all monitoring studies. Of the PFAS analyzed, PFOS readily accumulates with average concentrations in whole fish ranging from less than 10 to greater than 100 ng/g.
- In the Delaware River Basin, sampling has been conducted over a 17-year period that coincided with actions to reduce or eliminate the release of certain PFAS to the environment. There have been decreases in perfluorononanoate (PFNA) and perfluoroundecanoate (PFUnA) concentrations observed in fish filets from the tidal river during the timeframe of the study, but changes in concentrations of other PFAS in tidal and non-tidal filets were less substantial.
- PFAS monitoring in the Puget Sound has been ongoing since 2013. Indicator species have been analyzed for 13 PFAS compounds and include juvenile and resident adult Chinook salmon, Bay mussel, English sole, and Pacific herring. PFAS concentrations in fish and shellfish whole bodies, fillets, and livers are in the ng/g range similar to other large watersheds with the highest concentrations in liver. Juvenile Chinook salmon, migrating seaward from rivers and streams, had the highest observed PFAS concentrations and number of detections.

Among the Great Lakes, Lakes Erie and Ontario have the highest PFAS concentrations. EPA and Environment Canada are providing resources for fish monitoring. Brian Lenell (EPA Region 5) shared information related to ongoing PFAS efforts and priorities within the Great Lakes. The standard method utilized in monitoring efforts is whole fish with isotope dilution analysis for sixteen long- and short-chain PFAS. PFOA is generally not found in Great Lakes whole fish. PFOS, however, does accumulate and average concentrations in whole fish between 2004-2018 were less than 10 ng/g to greater than 100 ng/g. PFAS atmospheric deposition methods are in development. Tributary water and sediment monitoring is being conducted by USGS and EPA Office of Research and Development (ORD). Ecological risks of PFAS to fish and wildlife are also being assessed by the EPA ORD. Wildlife monitoring is underway by USGS, who is monitoring PFAS in tree swallows at Great Lakes areas of concern, and U.S. Fish and Wildlife Service (FWS), who is studying PFAS effects on survival of endangered native freshwater mussels. A fish consumption advisory monitoring grant program exists for Great Lakes states.

Ron MacGillivray (Delaware River Basin Commission) presented an overview of ongoing efforts investigating PFAS in fish fillets, surface water, and sediment from the Delaware River over a 17-year period (2004 to 2021). The sample period coincided with actions to reduce or eliminate the release of certain PFAS to the environment. Elevated levels of PFNA and PFUnA were initially observed in tidal fish fillets. While decreases in PFNA and PFUnA concentrations were observed in filets from the tidal river during the timeframe of the study, only minor changes were identified for other PFAS. Fish fillets continued to be contaminated with PFOS at levels exceeding recommended risk advisory limits on fish consumption (Figure 3) which range from 0.2-50 µg/kg for one meal/week depending on the state (ECOS, 2020). Sediment contained long-chain PFAS (PFAS compounds with more than six carbons, examples include PFOS and PFOA) at low concentrations. Surface water samples contained elevated levels of PFUnA and PFNA in areas not designated for drinking water sources with apparent decreases over the sample period. In main stem Delaware River segments designated as drinking water sources, PFAS were below the adopted and proposed maximum contaminant levels (MCLs) by Delaware River basin states. Additional studies of legacy and emergent PFAS are planned to evaluate the efficacy of regulatory and management strategies in reducing exposure and risks from PFAS to human health and aquatic life.

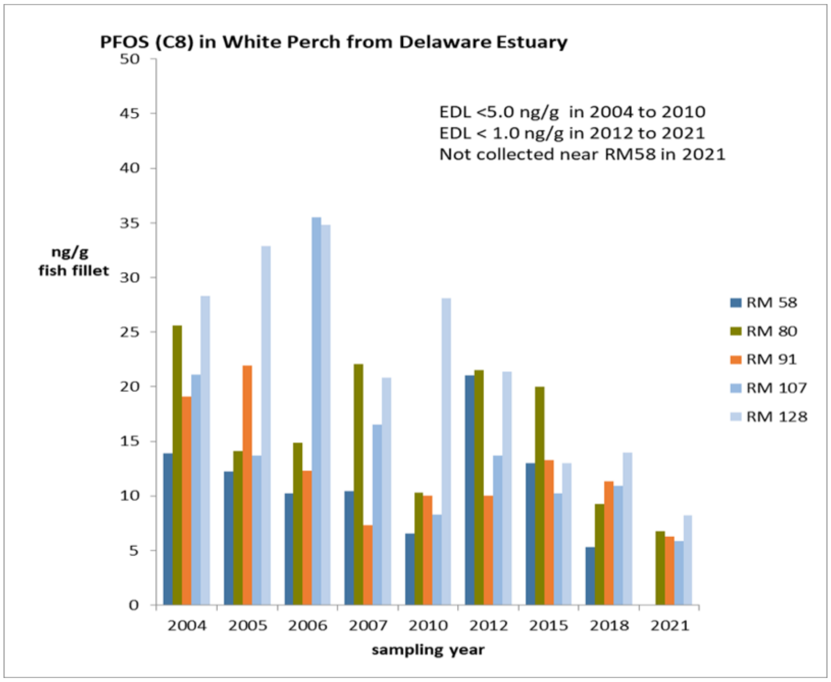

Figure 3. Spatiotemporal changes in perfluorooctanesulfonate (PFOS) concentrations in white perch fish fillets collected from the Delaware Estuary according to river mile (RM). The estimated detection limit (EDL) for PFOS is also included.

Washington Department of Fish and Wildlife (WDFW) began monitoring PFAS in Puget Sound fish and shellfish in 2013, and these efforts were discussed by Louisa Harding. Indicator species from each major habitat have been analyzed, including juvenile Chinook salmon (riverine/estuarine), Bay mussel (nearshore), English sole (benthic), Pacific herring, and resident adult Chinook salmon (pelagic; Figure 4). Overall, PFAS concentrations in fish and shellfish whole bodies, fillets, and livers are in the ng/g range. Paired fillets and liver or whole body and liver samples revealed higher concentrations in liver. The highest PFAS concentrations and detection rates occurred in juvenile Chinook salmon, migrating seaward from rivers and streams. Levels of PFAS in Puget Sound biota were generally below published adverse concentrations for fish and shellfish; however, some of these concentrations could pose a risk to avian or mammalian consumers, including endangered Southern Resident killer whales. Concentrations detected in fish from Washington were lower than EPA's draft criteria for PFOA (6,100 ng/g) and PFOS (6,750 ng/g) in freshwater for the protection of aquatic life released in April 2022.

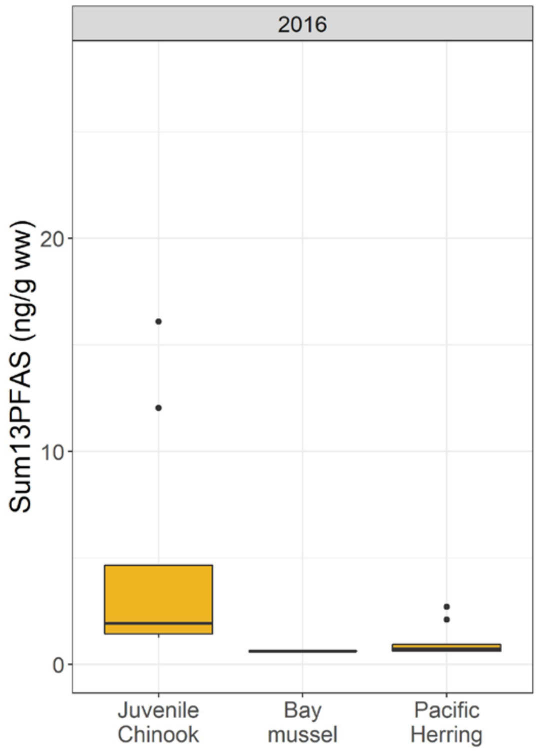

Figure 4. Sum of 13 PFAS compounds (ng/g wet weight) in fish and shellfish samples collected from the Puget Sound in 2016. Concentrations were below the Canadian federal wildlife dietary guideline for PFOS (4.6 ng/g dry weight whole body) and EPAs draft criterion for PFOS in freshwater species (6,750 ng/g wet weight whole body).

Identified Key Knowledge Gaps

There were several breakout sessions during the workshop where participants provided input on knowledge gaps and priorities that should be considered for the Chesapeake Bay Watershed. The questions (in bold/italics) and input for the first breakout session are listed below.

Are there key findings and efforts associated with sources, occurrence and fate that are missing from the Chesapeake Bay Watershed?

The group identified several key findings/efforts that were missing from the Chesapeake Bay Watershed specifically related to sources, occurrence, and fate. Identification and isolation of specific sources was considered a priority need. For example, studies specifically designed to identify legacy and active sources using information on the presence or absence of branched versus linear isomers, as well as more detailed PFAS fingerprinting, should be prioritized. More comprehensive systematic monitoring and profiling of PFAS throughout the Bay and its tributaries with an emphasis on both point and nonpoint sources are also needed to understand and document inputs from smaller urbanized tributaries. Information on sources and the occurrence of different PFAS mixtures is important for continued assessment of mixture toxicity, trophic transfer, and eventual incorporation into food web modeling.

What are the jurisdictional priorities in the Chesapeake?

Emphasis has been placed on assessing PFAS in drinking water across the watershed in both public supplies and potable wells in support of human health outcomes. Jurisdictions are also expanding sampling in surface waterbodies, including long-term storm and ambient monitoring locations, with an emphasis on freshwater systems. Over the past few years, states have also started assessing PFAS in aquatic organisms, including fish, mussels, oysters, and crabs.

What are the highest priority knowledge gaps related to sources, occurrence, and fate in the Chesapeake Bay?

Studies designed specifically to systematically monitor PFAS throughout the Chesapeake Bay watershed have not been a priority. More information on PFAS profiles (beyond aqueous film forming foam [AFFF] impacted sites) and estimates of concentrations throughout the Bay watershed are needed. There is also a need to develop an improved understanding of what land uses are most likely to contribute to PFAS concentrations, and whether this information can be used to predict occurrence, delivery, and load into unmonitored locations.

Considerations for Establishing PFAS Thresholds: Effects on fish and wildlife, and their consumption by humans.

One of the primary knowledge gaps identified in the STAC workshop proposal was better understanding of the occurrence of PFAS in fish and wildlife. Jurisdictions are keenly interested in the potential risk to human health from consumption of fish and shellfish and said this is the optimal time to understand what is needed to develop fish-consumption advisories for PFAS. This session focused on talks to improve the information and options for developing fish consumption advisories and studies to assess effects of PFAS on fish and other aquatic organisms. ***Please note that this workshop was conducted prior to the release of EPA's new interim health advisories (HAs) release in June 2022 (EPA, 2022a). All reference doses for consumption advisories are based on previous HAs for PFOS and PFOA released by EPA in 2009 (EPA, 2009).***

A summary of notable findings provided by the speakers include:

- New Jersey was one of the first states to establish fish consumption advisories for PFAS and has developed trigger levels for PFOA, PFNA and PFOS. The state has included PFAS in their statewide monitoring. When the trigger levels were established, all waterbodies near a known PFAS source required some level of a consumption advisory due to PFOS. Trigger levels were established based on 2016 reference dose data generated by EPA.
- Tentative results from the regular fall fish collection in Maryland showed no levels of concern that would prompt further investigation in the harbor, bay, and metro regions. As

data were gathered from the fall 2021 sampling, two clear conclusions started to form: most sites throughout Maryland have a total targeted PFAS concentration of < 10.0 ng/L for surface water and <10.0 ng/g wet weight for sampled fish tissue; and surface water PFAS concentrations are an important indicator of PFAS in resident fish species tissue.

- Four PFAS compounds were detected in every fish plasma sample collected from several sites within the Potomac and Susquehanna River watersheds, including PFOS, PFUnA, perfluorododecanoate (PFDoA) and PFDA. Perfluorooctanesulfonamide (PFOSA) and PFNA were also detected in some of the sampled fish.
- Many of the studies conducted on AFFF impacted sites and funded through the Strategic Environmental Research and Development Program (SERDP) program have concluded 1) that PFOS (and maybe perfluorohexanesulfonic acid [PFHxS]) drives risk at legacy AFFF impacted sites, 2) mixture effects observed thus far are highly variable and inconsistent across species, endpoints, and life stage, and 3) PFAS free foams may also be acutely toxic to freshwater species but there remains a high variability among products. More data across products, concentrations and species are needed to fully evaluate the potential effects. Studies funded through the program have also developed bioaccumulation factors and toxicity reference values (TRVs) for an increasing number of PFAS and receptors.

Developing Fish Consumption Advisories

Sandra Goodrow (Division of Science and Research, New Jersey Department of Environmental Protection) provided a presentation on the development and application of fish consumption advisories in New Jersey. The information included a brief introduction to the statewide program for fish consumption advisories, which is a tiered approach (i.e., statewide, regional, and waterbody specific advisories) that collects samples from waterbodies across the state on rotation, completing the entire state every five years. The investigation of PFAS in fish tissue began in 2016 with an initial assessment of 11 waterbodies that were targeted due to their proximity to a potential PFAS source and popularity with anglers. Results from the surface water and sediment analysis were used to determine PFAS partitioning coefficients, which suggested that long-chain PFAS preferentially partition to sediments, and short-chain PFAS are primarily found in the aqueous phase. PFOS was the dominant PFAS in the fish tissue. New Jersey developed the fish consumption advisory “trigger levels” by using the 2016 EPA recommended reference dose (RfD) calculated for use in the development of the MCLs for PFNA, PFOA, and PFOS (Table 1). The trigger levels are tied to unlimited, weekly, monthly, once every three months, and once per year consumption recommendations. The most restrictive advisory is “Do Not Eat”. When the triggers were applied to the sampled waterbodies, every location required some level of consumption advisory, often due to the concentration of PFOS in the fish tissue. Advisories ranged from once per week in some waterbodies for select species to no more than once per year in waterbodies located near a military base known to have AFFF releases.

Table 1. New Jersey Department of Environmental Protection fish consumption advisories (ng/g).

	PFOA	PFNA	PFOS
Unlimited	≤ 0.62	≤ 0.23	≤ 0.56
Weekly	≤ 4.3	≤ 1.6	≤ 3.9
Monthly	≤ 18.6	≤ 6.9	≤ 17.0
Once/3 months	≤ 57.0	≤ 21.0	≤ 51.0
Yearly	≤ 226	≤ 84.0	≤ 204
Do Not Eat	> 226	> 84.0	> 204

Tom Ihde (Morgan State University, MSU) presented an overview of a pilot study that applies an existing spatial ecosystem model, the Chesapeake Atlantis Model, to estimate concentrations of PFOS based on biomagnification through the trophic structure of the system. The biogeophysical modeling approach allows simultaneous estimation of contaminant concentrations spatially throughout the brackish portions of the system and accounts for movements of contaminated water, plankton, and consumers. Consumer movement is estimated based on swimming speed and prey and refuge availability, along with the seasonal physical constraints of the system. Initial runs of the model will be based on values and estimates in both published and unpublished literature, as well as field data (e.g., collected by the Maryland Department of the Environment) for concentrations and rates of absorption, accumulation, and depuration for flora and fauna in the model. Bioaccumulation across trophic levels is not always predictable by trophic position. Although initial model runs are expected to produce relative levels of contrast for contamination across the system for any species, target species must be field tested to tune the model to scale outputs to observed levels of contamination. Blue Crab is a valuable seafood in the Chesapeake Bay and will serve as the initial test species for this pilot study. Two areas of the Chesapeake Bay, that the model predicts will have relatively strong contrasts in PFOS concentrations for Blue Crab, will be sampled in the coming year as close to the same time as possible. Animals collected from both sites will be tested for actual concentrations of multiple PFAS to tune model outputs to observed PFOS concentrations in Blue Crab (whole body). Quantification of PFAS contamination for Blue Crab samples will be made by Lee Blaney and his staff (University of Maryland Baltimore County). Similar field testing will be required to identify relative differences between target species. A second (still unfunded) phase of follow-up study will be required to perform tuning of the model for Striped Bass and Blue Catfish, since both are high-priority, heavily targeted seafood species in the Chesapeake watershed. This approach could provide a cost-effective complement to the intensive and costly spatial sampling required of more traditional contaminant monitoring, while also accounting for the rapid movements expected of contaminated predators. This study is funded by the National Institutes of Health through MSU (Award Number 5U54MD013376) to address concerns of human health disparities related to risks associated with consumption of PFAS-contaminated seafood. Subsistence fishers may be especially at risk in areas where PFAS sampling would not otherwise be conducted due to the absence of known point sources.

Amy Laliberte (Maryland Department of the Environment, MDE) provided an overview of MDE's work on PFAS in surface water crabs, oysters, and fish. PFAS efforts in Maryland are focused around three goals: (1) understanding the risk through sampling, science, and assessment, (2) communicating the risk through public information and outreach; and (3) reducing unacceptable risks through appropriate funding, regulation, partnerships, and agency coordination. MDE is putting a priority on the implementation of a science-based comprehensive plan for PFAS risk that is focused first on determining whether there are locations in Maryland where there are unacceptable risks to human health associated with exposures to PFAS and whether there are locations of continuing releases of PFAS compounds. Focused efforts on PFAS occurrence in water, fish tissue, and oysters were conducted in several locations, including St. Mary's River, Piscataway Creek, and Eastern Shore tributaries, starting in 2020. In fall 2021, MDE began its strategic sampling of fish tissue for PFAS in harbors, bays, and metro regions. A total of 28 individual sites were sampled, leading to collection of 26 surface water samples and 68 fish composites. The tentative results from the regular fall fish collection showed no levels of concern that would prompt further investigation in the harbor, bay, and metro regions. As data were gathered from the fall 2021 sampling, two clear conclusions started to form: most sites throughout Maryland have a total PFAS concentration of < 10.0 ng/L for surface water and <10.0 ng/g wet weight for fish tissue; and surface water PFAS concentrations are an important indicator of PFAS in resident fish species tissue. Of the results collected thus far, six of the sixteen sites had surface water concentrations greater than 10.0 ng/L (i.e., 12.0 - 36.0 ng/L), and five of those six sites exhibited greater than 10.0 ng/g PFAS in fish tissue. No site that had surface water concentrations less than 10.0 ng/L had fish tissue concentrations (predator or accumulator species) greater than 10.0 ng/g. MDE derived screening values based on the 2016 EPA RfDs for PFOS, PFOA, and other PFAS with peer reviewed RfDs at the time the data were evaluated (these values have not been updated after the July release of the EPA interim HA). Exposure assumptions to derive oyster and fish consumption screening concentrations, as well as recreational surface exposure while swimming and wading, were based upon MDE consumption rates, conservative exposure frequencies, and site-specific factors. Data appear to indicate certain PFAS, especially PFOS, have substantial variability between fish species and do not appear to accumulate in certain mollusks and crustaceans, but additional data are necessary to validate these cursory findings. The dominant compound identified in fish tissue was PFOS. Species like channel catfish had significantly less PFAS than largemouth bass, sunfish, and perch, but questions on species diet and food chain dynamics exist. To date, PFAS have not been identified in mollusks in the Chesapeake Bay. Analysis of crustacean samples is ongoing. As updates to current RfDs are advanced and new RfDs are developed, MDE will update fish consumption advisories.

Understanding Potential Toxic Effects on Aquatic Organisms

Heather Walsh (USGS) presented on the spatial and temporal variation of PFAS in smallmouth bass plasma and associated effects (Blazer et al., 2021). Smallmouth bass have faced ongoing health issues in the Chesapeake Bay watershed, including fish kills, skin lesions, reproductive endocrine disruption (intersex), and parasite and pathogen infections. Poor water quality and contaminant exposures, including PFAS, have also been documented, and the combination of these factors has led to population declines in some areas of the Potomac and Susquehanna River watersheds. Biological effects monitoring at the molecular, cellular, organ, and organismal levels has occurred at four sites (i.e., two in the Potomac, two in the Susquehanna River watersheds) influenced by agricultural land use. In 2018, archived plasma from bass sampled at these sites were sent to SGS-AXYS Analytical Laboratory for analysis of 13 PFAS (9 perfluorocarboxylic acids and 4 perfluorosulfonates). Four compounds were detected in every fish, including PFOS, PFUnA, perfluorododecanoate (PFDoA), and PFDA, and perfluorooctanesulfonamide (PFOSA) and PFNA were detected in some fish (Figure 5). No seasonal differences were identified. However, site differences were observed, with the highest PFOS, PFUnA, PFDoA, and PFDA concentrations at the site with the most pesticide and biosolid applications in the upstream catchment (i.e., Antietam Creek/Potomac River confluence; Potomac River watershed). When all sites and seasons were combined, concentrations of PFDoA and PFUnA were higher in males than in females; when sex differences were analyzed at each site, the same finding was observed. Only PFDA was higher in males at the primarily forested site, Pine Creek (Susquehanna River watershed). Following these initial observations, plasma from bass sampled at these four sites in 2017 and 2019 was also analyzed to identify temporal differences and associations between PFAS and biological endpoints, including plasma vitellogenin, condition factors, histopathological findings, liver gene expression, and immune function. Plasma was also analyzed from additional sites for a larger spatial analysis and better understanding of sources. This analysis still showed that Smallmouth bass from Antietam had the greatest levels of PFOS and total PFAS, but a decrease in plasma PFAS levels occurred over time at some sites. Another finding was from one of the additional sites on Swatara Creek in the Susquehanna River watershed, which had even higher levels of PFOS (up to 864 ng/mL) than Antietam. Analyzing PFAS tissue distribution in muscle, liver, gonad, and whole blood, and including a broader suite of 40 PFAS could facilitate understanding the effects of PFAS on immune function and the health of smallmouth bass.

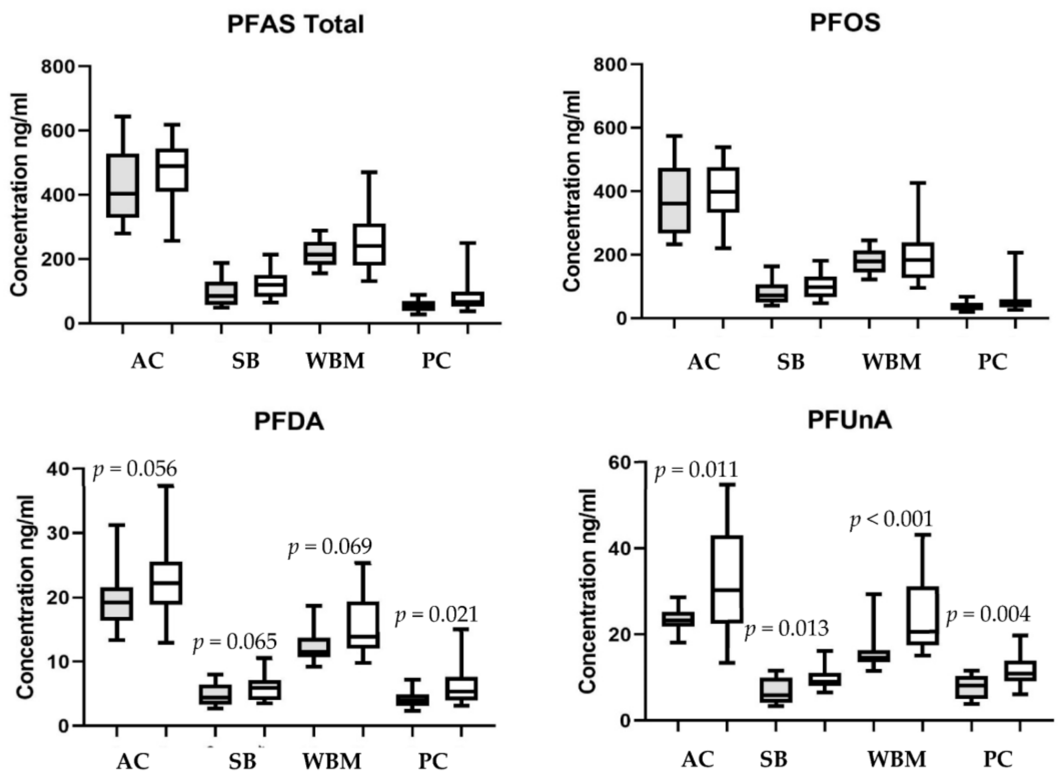

Figure 5. Comparison of PFAS in female (gray bars) and male (white bars) smallmouth bass plasma from the Antietam Creek (AC), South Branch Potomac (SB), West Branch Mahantango (WBM) and Pine Creek (PC) sites. Box plots show minimum and maximum values, the median, and interquartile ranges. p-values indicate difference between male and female at that site. There were no significant differences at any sites for total PFAS or PFOS. From Blazer et al. (2021).

The Strategic Environmental Research and Development Program (SERDP) is the environmental research program for the Department of Defense (DoD) that has supported much of the ecologically focused PFAS research over the last few years. Hunter Anderson (U.S. Air Force) gave a brief overview of the ongoing and completed research funded by SERDP with an emphasis on avian receptors, reptiles, and amphibians. Since 2012, SERDP has awarded over 200 million dollars in support of 15-20 projects with an emphasis on ecotoxicology. One of the SERDP funded projects produced a guidance document designed to assess the ecological risks of PFAS to threatened and endangered species specifically at AFFF impacted sites (Conder et al., 2020). The report recommended values for 18 target PFAS compounds including bioaccumulation factors to predict uptake by aquatic and terrestrial biota, wildlife toxicity values, aquatic life criteria and plant/invertebrate soil criteria. The guidance was based on a comprehensive review of over 250 studies in which 200 toxicity values and 1,300 bioaccumulation values were considered. The report also indicated that single digit µg/g concentrations could indicate concern for some species and emphasized the need for more studies designed to address PFAS mixtures and the utility of non-target analysis (NTA) to identify unknown compounds. Several projects focused on the effects of PFAS on avian receptors under laboratory conditions indicating mixture effects were only observed in females (e.g., PFOS + PFHxS and PFOS + PFHxA [perfluorohexanoic acid]; Dennis et al., 2020; 2021). The study also calculated toxicity values (mg/kg/d) and found effects on egg production (PFHxS), hatching success (PFOS) and chick weight (PFHxA; Dennis et al., 2021). Other scientists have been using SERDP funding to establish reptilian TRVs and document mixture effects. For example, PFHxS contributes to reptile toxicity only in the presence of PFOS indicating a synergistic effect. Ongoing work with amphibians has focused on bioaccumulation and effects on survival, growth, and development. PFOS was the only PFAS that bioaccumulated in amphibians and 6:2 FTS (fluorotelomer sulfonate) was metabolized quickly. Species sensitivity to PFAS varied and toads were the least sensitive followed by salamanders and frogs, while effects on growth, development and condition factor ranged from 10-100 µg/L. These studies and others funded through the SERDP program have identified some fundamental conclusions to date including 1) PFOS (and maybe PFHxS) drives risk at legacy AFFF impacted sites, 2) bioaccumulation factors and TRVs are available for an increasing number of PFAS and receptors and 3) mixture effects observed thus far are highly variable and inconsistent across species, endpoints, and life stage.

Jamie Suski (EA Engineering, Science and Technology, Inc) gave an overview of studies designed specifically to address toxicity of PFAS (emphasis on PFOS, Figure 6) and potential firefighting foam replacements. Many of the studies conducted by EA involve the use of fathead minnow to understand the effects of PFAS on critical life stages including reproduction and development. Juvenile fathead minnows were the most sensitive to PFOS with effects on growth at 88 µg/L (Suski et al., 2020). PFOS also showed an effect on reproduction with a decrease in the number of spawning events per day in females at concentrations > 140 µg/L. Mixture studies with PFOS, PFNA and PFHxS indicate PFOS is driving toxic effects compared to the other PFAS tested and larval life stages tend to be more sensitive than adults. Similar to other studies, PFOS concentrations in tissues (ovary, brain, etc.) are higher than other PFAS compounds measured. Further, PFAS free foams may also be acutely toxic to freshwater species but there remains a high variability among products and more data across products, concentrations and species is needed to fully evaluate the potential effects.

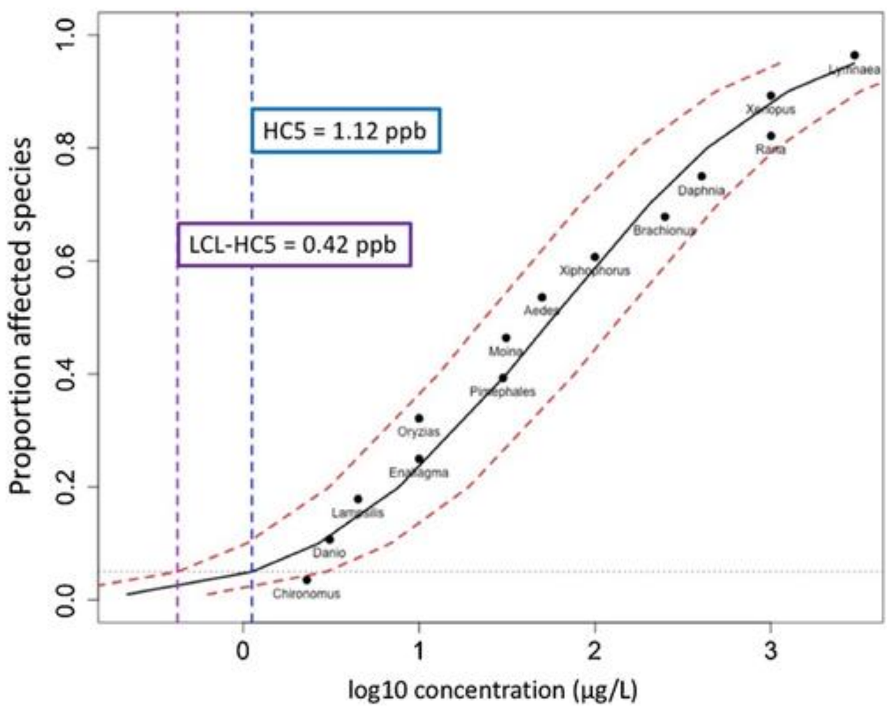

Figure 6. Species-sensitivity distribution (SSD) for chronic PFOS toxicity data for freshwater species. The SSD was used to estimate the 5% hazardous concentration (HC5) and the 95% lower confidence limit (LCL) of the HC5. The black dotted horizontal line represents the HC5, the blue dashed line corresponds to the log10 PFOS concentration at the HC5, and the purple dashed line is the 95% LCL of the HC5. From Salice et al. (2018).

Limited information is available on PFAS presence and persistence in the marine environment and its effects (chronic) on marine fish, shrimp, and bivalves. Marie DeLorenzo (National Oceanic and Atmospheric Administration [NOAA], National Centers for Coastal Ocean Science [NCCOS]) discussed NOAA's work to help managers detect PFAS in coastal, marine, and Great Lakes environments, to understand the biological effects of PFAS, and to mitigate those impacts. In this regard, NOAA conducts environmental sampling, laboratory toxicity testing, field and mesocosm studies, and ecological forecasting and works closely with federal/state agencies to translate their data into technological solutions and management actions that mitigate pollution impacts and protect the sustainable use of coastal resources. NOAA/NCCOS is establishing acute toxicity thresholds for larval fish and invertebrates for both PFAS (Figure 7) and alternative PFAS-free AFFF. Preliminary results indicated that the most sensitive species were larval mud snails, followed by sheepshead minnows, grass shrimp, and oysters. Toxicity and bioaccumulation of PFOS in grass shrimp and sheepshead minnow varied by both temperature and salinity. Studies designed to develop acute and chronic toxicity thresholds for AFFF formulations are being conducted by NOAA and others. Chronic tests are ongoing, but acute studies indicated variable toxicity of AFFF formulations for a wide variety of organisms (Figure 7). In the marine environment, mixture studies included PFOS, PFOA, and PFHxS, and preliminary data indicated that larval sheepshead and juvenile red drum were the most sensitive species. This information can be used by EPA when setting marine water quality criteria for PFAS. Lastly, the NOAA Mussel Watch Program conducts regional monitoring of 28 PFAS compounds in sediment and bivalves and contributes to building a national database that provides coastal resource managers with baseline information on the magnitude and distribution of PFAS in the coastal environment (Apeti et al., 2018). PFAS work is being conducted on oysters in the southeastern United States (i.e., South Carolina to Florida, including the Gulf of Mexico) and blue mussels and Eastern oysters in the mid-Atlantic (i.e., Massachusetts to North Carolina).

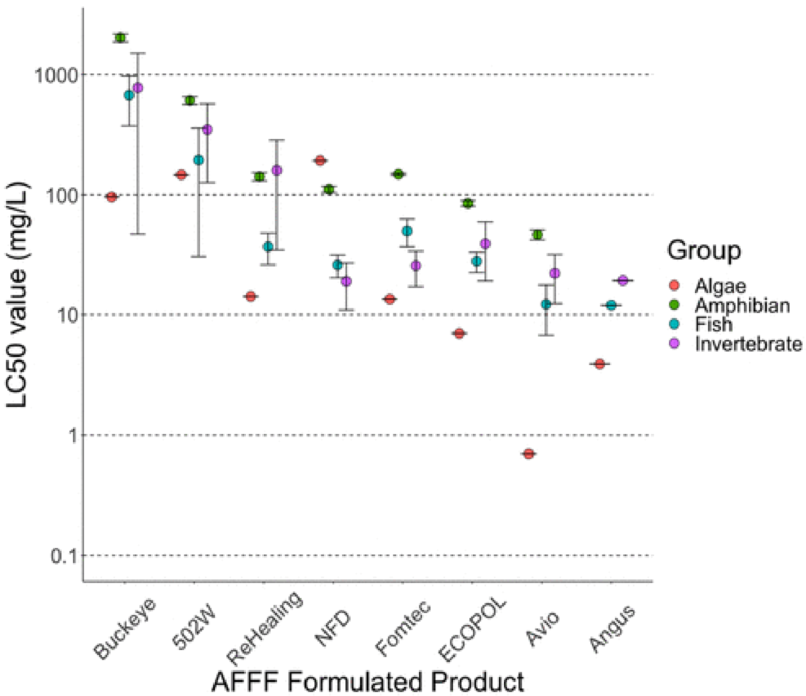

Figure 7. Calculated effects concentration (EC50; algae) and lethal concentration (LC50) values for taxonomic groups. Data points represent taxonomic mean ±1 standard error and include only those species with calculated toxicity values. From Jones et al. (2022).

Identified Knowledge Gaps

The questions posed to the workshop participants (in bold/italics) and their input for the second breakout session are listed below.

Are there key findings or efforts for PFAS ecotoxicity which are missing for the Chesapeake Bay?

Broad studies on ecotoxicology are limited by species, individual PFAS and life-stage. Much of the discussion centered around PFAS mixtures for toxicity testing and how to adequately identify what should be tested and in what species. For example, in the Bay watershed, there needs to be a better understanding of regional PFAS mixtures and ratios with an emphasis on other sources besides AFFF impacted sites and smaller watersheds. Also, there is a need for more studies to look at the interface between the aquatic and terrestrial ecosystems including more studies on waterfowl, fish eating birds, and mammals. Understanding paternal/maternal transfer and differences in sensitivities between sexes and life-stage is also a knowledge gap.

What are the highest priority knowledge gaps related to ecological effects in the Chesapeake Bay?

Currently, more information is needed on chronic toxicity for a broader range of species and life-stages including larval oysters and blue crabs, both staples of the Bay's ecosystem. Also studies specifically relating PFAS concentrations/exposure to potential ecological health outcomes including cumulative effects of other contaminants and stressors. To understand effects, there must be a broader understanding of PFAS mixtures across a range of sources. For example, monitoring smaller streams/tributaries could help identify sources and tease out potential PFAS mixtures of concern. For the development of consumption advisories across jurisdictions, it would be helpful to develop a uniform bioconcentration factor approach.

Considerations for Developing a Coordinated Monitoring Effort for PFAS in the Chesapeake Bay

Another major knowledge gap was to identify a coordinated study approach with common, cost-effective monitoring and analysis methods and tools so results can be shared between states and agencies. The identification of sources, as well as sampling and analytical methods for PFAS, particularly in fish tissue, are rapidly evolving. Field studies of concentrations in fish, which are used to establish jurisdiction fish consumption advisories, could benefit greatly from a more coordinated study approach with consistent and standardized methods across the watershed. This section summarizes information from several speakers and the associated knowledge gaps.

A summary of notable findings provided by the speakers include:

- Drinking water and surface water sampling are the primary focus of current monitoring efforts by jurisdictions in the Chesapeake Bay watershed.
- Sample collection, preparation and analytical methods are not standardized which makes data comparisons across study and matrix (water, sediment, tissue) difficult and underscores the importance of communication and transparency among partners wishing to compare and share data.
- For tissue analysis, because PFAS preferentially binds to specific proteins, blood and liver are useful for monitoring in addition to edible portions that approximate potential human exposure.

Summary of existing methods and study designs

Currently, jurisdictions and researchers are independently making decisions about sampling and analysis methods. Appropriate selection, benefits/drawbacks of various methods in water and tissue are common questions. Coordinating these approaches now will support coordinated monitoring efforts and allow for data assessment at a broader scale.

The study design, types of samples collected, and analytical methods were compiled for PFAS efforts in the Chesapeake Bay watershed using information from the responses to the inventory questions distributed prior to the workshop to regulators and researchers at federal and jurisdiction agencies and public sources available on web pages for these agencies (Figure 8).

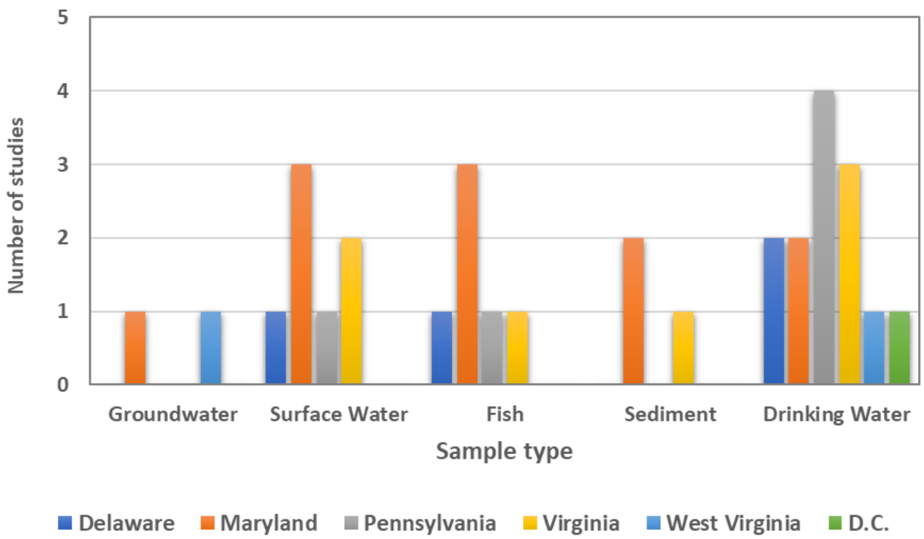

Figure 8: Sample types collected as part of PFAS sampling programs completed by the jurisdictions in the Chesapeake Bay watershed

Drinking water and surface water sampling are the primary focus of current sampling efforts by jurisdictions in the Chesapeake Bay area, whereas groundwater and sediment sampling for PFAS occurrence are part of studies reported in only two of the state jurisdictions. Most agencies reported one-time sampling to date with a phased approach planned to collect samples at additional locations, although more frequent monitoring in hotspots is also ongoing or planned. Temporal studies of surface water PFAS concentrations are planned in several states. Sampling methods have mostly involved grab samples, except one surface water study in Pennsylvania that collected grab samples and time-averaged passive samples. Fish sampling has been conducted in each of the states where surface water samples were collected for PFAS analysis. The PFAS levels in fish have generally been reported for fillet composites of different targeted fish species, including tidal and nontidal species. To prevent size bias, fish of similar weight and length were preferred for analysis. Oyster samples collected for a Maryland study were composited, and PFAS levels in oyster meat were compared to those in combined oyster meat and liquor. Analytical methods in the watershed have generally included analysis of 2 to 33 PFAS via EPA Method 537.1, EPA Method 533, or equivalent methods in state or commercial laboratories. A surface water study in Pennsylvania also analyzed samples for total oxidizable precursors (TOP), as well as target PFAS compounds, to provide a more inclusive calculation of total PFAS. Few analytical laboratories are currently available for fish tissue analyses and many completed studies have used the same laboratory (SGS AXYS in Sidney, British Columbia, Canada). EPA draft Method 1633 (EPA, 2022c) for targeted PFAS analysis in environmental media could be used in studies to support data comparability and consistency across the watershed. ***Please note that this workshop was conducted prior to the release in June 2022 of the second draft Method 1633 (EPA, 2022c).***

Anna Ruth Robuck (Icahn School of Medicine at Mount Sinai) summarized methods and challenges surrounding the analysis of PFAS in biological tissues. The presentation discussed species and tissue selection, and her examples indicated that the unique physicochemical characteristics of PFAS require reassessment of species and tissues used for monitoring. PFAS preferentially bind to specific proteins, making tissues like blood and liver useful for monitoring alongside edible portions that approximate potential human exposure. Perfluoroalkyl acids are the most salient compounds for analysis, but it is vital to consider the utility of applied methods for a wider array of compounds given the vast and rapidly growing size of the PFAS class.

Robuck indicated that PFAS concentration patterns in water are not necessarily reflected in sampled tissues, which complicates the development of bioconcentration factors. This phenomenon is likely due to the higher carbon chain PFAS binding to proteins in blood and liver. Differences were also observed between legacy and emergent PFAS occurrence in tissues. PFAS were not detected in mussels, indicating that they are not a good indicator species. Robuck suggested that considerations for the sampling of tissues should include:

- Reassessment of species
- Migratory status of the species
- Compartment of interest - differing bioaccumulation between benthic and pelagic
- Respiratory matrix (air vs. gill)
- Salinity impact on bioaccumulation; and
- Reference dose.

Robuck concluded the presentation by touching upon the importance of standardizing sample preparation, noting that different preparation and analytical methods are associated with different data artifacts. She suggested that liver samples should be prioritized for analysis of perfluoroalkyl acids. Likewise, different materials and handling can impact derived observations, underscoring the importance of communication and transparency among partners wishing to compare and share data.

Joseph Duris (USGS Pennsylvania Water Science Center, PAWSC) presented highlights of the work their center has been conducting since 2015 on PFAS occurrence, fate, and transport. This extensive study was conducted in cooperation with the Pennsylvania Department of Environmental Protection and led to the development of quality control procedures and lessons learned for large, field efforts. Samples were collected from surface waters around the state and analyzed using EPA Method 537.1 (Schoemaker and Tettenhorst, 2020). In 2019, the USGS PAWSC undertook an extensive sampling of the State of Pennsylvania Surface Water Quality Network (WQN). To ensure robust data from this sampling effort, 50 equipment blanks were collected prior to sampling the 178 surface water sites of the WQN. In addition, 18 field blanks, 18 field replicates, 10 composite split samples, and 18 polar organic chemical integrative sampler (POCIS) comparisons were conducted. No systematic bias was detected in the equipment blanks or field blanks. Field replicates showed a mean absolute difference of 1.5 ng/L in samples where a PFAS compound was detected. Replicate samples (i.e., a sample split between two labs using different analytical methods) demonstrated differences in both frequency of PFAS detection and PFAS concentration. POCIS samplers were able to detect more PFAS in water and at lower concentrations than discrete, grab samples. These studies demonstrated that care must be taken with both sampling and analytical methodologies to produce comparable datasets for PFAS.

Identified Knowledge Gaps

Participants were split randomly into three breakout groups (two online and one in person) and asked the following questions (in bold/italics).

What are barriers to having more consistency in approaches to monitoring and analyses across the watershed?

Several barriers were identified by the breakout groups, including a lack of consistency among methods and laboratories contracted by jurisdictions and researchers, funding constraints, a lack of coordination among agencies and jurisdictions, and overarching differences in objectives among academia and state/federal agencies. Reporting a total PFAS concentration (i.e., sum of all PFAS detected) depends on the method and measured compounds, which are not always consistent across studies. Currently, human health concerns related to drinking water sources are driving regulation and taking precedence over other PFAS issues (e.g., fate/transport, ecological health). State agencies are prioritizing drinking water concerns, while researchers and federal agencies are taking a more holistic approach to PFAS. Within the Bay watershed, priorities and objectives could be discussed more broadly and frequently among groups to foster collaboration and information sharing. Workshop participants also agreed that once EPA draft Method 1633 is approved (***note in June 2022 after the workshop had concluded, EPA released a 2nd draft Method 163***3), consistency among methods at the jurisdiction level would be improved. The participants also recommended that STAC advocate for method consistency across the Chesapeake Bay Watershed when designing and supporting monitoring programs.

Which methods should be utilized and how do we recommend consistency (e.g., EPA methods, non-target analysis; precursor analysis; extractable organofluorine)?

The selection of an appropriate method will depend on the objectives and focus of each study; however, reporting the analyzed compounds and corresponding detection limits should be clear and consistent for all studies. For example, if the study objectives are more regulatory focused, a targeted list of analytes using an approved method (e.g., EPA draft Method 1633) could be employed. If the study focuses on PFAS fate and transport, targeted, non-targeted, and TOP methods would be important to consider comprehensive changes in PFAS composition. Workshop participants agreed that non-targeted analysis could be used as a screening tool in areas where data are limited, followed by an approved method for regulatory purposes. From an ecological perspective, analytical methods that include PFAS compounds with EPA toxicity values (e.g., RfDs) are important for assessment purposes and should be prioritized. For coordination and informational purposes, the Bay Program should consider developing and maintaining a database of PFAS compounds, methods, detection limits, and approved laboratories within the Chesapeake Bay Watershed.

Which chemicals or bulk groupings (e.g., PFOS/PFOA; precursors; 24 or 40 compounds)?

The answer to this question depends on the scope, aims, and objectives of the proposed study. From a regulatory perspective, an EPA approved method utilizing an approved laboratory with a standard list of compounds should be prioritized with an emphasis on legacy compounds like PFOS and PFOA. Screening methods and/or bulk grouping could be important to prioritize during an initial pilot effort specifically related to occurrence, fate, and transport followed by more focused analysis of individual compounds determined to be important. A tiered approach could also be more cost effective and allow for a more robust assessment across more sites in each watershed to identify areas of interest for detailed study. To address PFAS more broadly and to compare data among sites and jurisdiction, similar methods/approaches should be adopted.

What tissues should we analyze (specific organ vs. whole animal)? And how (e.g., raw/cooked, etc.)?

The type of tissues selected for analysis would depend on the scope, aims, and objectives of the study. PFAS preferentially binds to specific proteins, making tissues like blood or liver useful for monitoring alongside edible portions that approximate potential human exposure (e.g., skin off fillets and/or whole fish). To address bioaccumulation/biomagnification of PFAS, whole animal studies are required since predators consume the whole prey.

Summary of High Priority Science Gaps and Associated Recommendations for More Coordinated Research & Monitoring Efforts for PFAS in the Chesapeake

During breakout sessions, workshop participants were asked to identify high priority knowledge gaps related to the sources, occurrence, fate, and ecological effects of PFAS in the Chesapeake Bay watershed with a goal of developing actionable recommendations for more coordinated research and monitoring efforts for PFAS in the Chesapeake Bay Watershed. Participants were then asked to categorize the identified gaps as 'research' or 'monitoring' using the definitions in the inset. All the gaps listed in Table 2 were identified as a research gap by most of the participants. However, SG1, SG2, and SG10 include gaps that could also be addressed through coordinated monitoring.

> **Monitoring**: the assessment of the quality of the environment in order to control the risk of pollution. More specifically, it is the process of sampling and analyzing specific environmental media (e.g., soil, water, tissue) for evidence of changes in contaminant levels over time
>
> **Research:** a careful and detailed study into a specific problem, concern, or issue using the scientific method. A systematic investigation including development, testing and evaluation designed to develop or contribute to generalizable knowledge and the establishment or revision of theories or laws.

Summary of High Priority Science Gaps and Suggested Timeline

After the conclusion of the workshop, the steering committee organized the topics in Table 2 into four categories related to the workshop objectives: 1) sources, fate, and occurrence, 2) exposure and bioaccumulation, 3) fish consumption, and 4) ecological effects. The steering committee used discussion from the workshop to suggest timeframes to address the science gaps. Gaps that should be addressed immediately were labeled "urgent, short term" with the other needs having different suggested timeframes. Most science gaps are not prerequisite to those listed with later timeframes.

Table 2: A list of high priority science gaps related to sources, occurrence, fate, and ecological effects of PFAS in the Chesapeake Bay watershed.

Science gap category (SG)	Description	Suggested timeframe to address gap
SG1: Source, fate, and occurrence	Temporal and spatial assessment of PFAS occurrence in tributaries, including first order streams, to determine where loadings are coming from with an emphasis on both point and nonpoint sources	Urgent, short-term
SG2: Exposure and bioaccumulation	Coupled fish and surface water samples to develop species-specific bioaccumulation factors ("early warning system"), including more regional studies to related surface water and tissue PFAS concentrations across a range of species using standardized methods	Urgent, short-term
SG3: Fish consumption	Development of a uniform bioconcentration factor approach regionally between the states to drive fish consumption advisories	Near-term
SG4: Ecological effects	Information on effects of PFAS on different life stages of fisheries in estuarine and freshwater systems	Near-term
SG5: Ecological effects	Studies addressing the biological effects of PFAS at lower concentrations	Near-to mid-term
SG6: Exposure and bioaccumulation	Studies directly designed to address food chain/ biomagnification of PFAS	Near-to mid-term
SG7: Source, fate, and occurrence	Better understanding of what land uses are most likely to contribute to PFAS detections and whether that information can be used to predict occurrence, delivery, and load	Near-to mid-term
SG8: Ecological effects	Cumulative effects of PFAS and other contaminant and biological stressors on aquatic species, synergistic effects that have the potential to enhance the risk of PFAS	Long-term
SG9: Ecological effects	Studies specifically designed to provide information on chronic toxicity for larval oysters and blue crabs with an emphasis on long-term exposures	Long-term
SG10: Ecological effects	Emphasize/prioritize more studies directly assessing the interface between the aquatic and terrestrial environments (e.g., ducks and other avian species)	Long-term

Recommendations to address the science gaps

A list of actionable recommendations was identified by the workshop participants to meet the science needs and help stakeholders better coordinate PFAS efforts to ensure data comparability across the entire Chesapeake Bay Watershed. We urge jurisdictions, federal agencies and academic researchers engaged in PFAS activities throughout the Chesapeake Bay Watershed to consider the science gaps and recommendations identified by the workshop participants when designing future PFAS research and monitoring studies. Coordination is essential and would require the creation of common study objectives that each jurisdiction, agency, or scientist would agree to collect based upon the media being sampled. This strategy would ensure the ability to conduct statistical analysis with "large" pooled data, allowing for a better understanding of PFAS occurrence, fate, transport, and source apportionment within the Bay and across the watershed. With the release of EPA Strategic Roadmap in 2021 (EPA, 2021), the PFAS landscape is rapidly evolving. After the conclusion of the workshop, the EPA released an updated draft Method 1633 for approval (EPA, 2022c) and updated interim HAs for PFOA, PFOS, PFBS and Gen X (EPA, 2022a). All suggested recommendations and science gaps are also rapidly evolving and should be reassessed periodically. Below is a summary of the suggested recommendations from the workshop participants and information on which science gap (SG) or gaps these recommendations fill (Table 2). These recommendations are organized by the science gap or gaps they fill and binned into three overarching themes by the steering committee

Theme 1: Communicate and collaborate

Enhance interaction between management agencies and scientists to facilitate broad coordination across the Bay watershed. Public outreach efforts could be conducted through a PFAS advisory board to help translate the information and subsequent potential risk. Utilizing news outlets that provide objective reporting could bring PFAS science to a broader audience. Further, to support technical information sharing, the Chesapeake Bay Program should support (1) additional capacity and staffing for coordinating PFAS activities in the Bay watershed and developing interim and decision-tree guidance for study design, sampling and analytical methods, (2) database development to store Bay-wide PFAS data, including appropriate data management and metadata storage, and (3) web page development (e.g. PFAS portal), including links to the developed database, a map of study locations, and a list of research and study points of contacts with areas of expertise. **Technical communication among scientists/managers and public outreach supports all gaps identified and are needed for better coordination across state and federal agencies and universities.**

Collaborate amongst jurisdictions to develop data needs for fish consumption advisories. The workshop revealed most jurisdictions lack data to establish thresholds for fish consumption advisories or to protect aquatic communities. Adoption of this recommendation could allow scientists and managers to identify tissue concentrations in support of assessing important thresholds for human health and health of aquatic communities. This would involve coordination of sampling designs and analytical methods and the types of tissues collected for analysis. If lethal sampling is employed for consumption advisory sampling, whole blood/plasma and other organs (i.e., liver) also should be collected**. This type of opportunistic sampling and coordination of efforts among jurisdictions and researchers would directly support SG3, SG4, and SG6 by providing data to support both human and ecological health.**

Theme 2: Study design and approaches

Design a monitoring network and specific approaches to directly address PFAS. The establishment of a new monitoring network focused directly on PFAS would be of benefit because of the ubiquity of PFAS, the complexity of the sources, and the limited information available on ecological effects. Additionally, developing new studies, identifying new sites, and species of concern which are directly focused on PFAS could enhance coordination among jurisdictions and other Chesapeake Bay researchers. Existing information should be included in a shared dashboard with known results and studies across jurisdictions as a useful tool to build collaboration and shared knowledge in the watershed. For example, widespread tributary monitoring in multiple media could help identify targeted mixtures in regions or geographic areas and be associated with sources (see SG1 in Table 2). This approach could also include the development and adoption of specific test bed sites that require active sampling for up to 5 years to address a broad range of priority science gaps through integration and collaboration among scientists. These sites could be modular and move around the Bay based on existing priorities and science questions. **This network directly supports the coordination and data collection needed to fulfill SG1, SG2, and SG7 and would support efforts designed to accomplish SG6, SG8, and SG10.**

Design studies that relate PFAS occurrence and effects in different land-use settings. The majority of PFAS studies is currently focused on military installations and needs to be expanded to other land-use settings. A specific land-use setting is in rural lands where biosolids application, septic systems, and other non-point sources, may potentially introduce PFAS to groundwater, soil, and food crops. Some states are proposing a moratorium on biosolids application to agricultural lands due to PFAS risk but data to support decision makers are insufficient currently. **Expanding research and monitoring to areas not directly impacted by military installation supports the science gaps outlined in SG1, SG2, and SG7 by providing information on PFAS occurrence and sources more broadly across the watershed.**

Theme 3: Consistency in data collection

Develop and adopt similar field collection and analytical approaches and methodologies to better compare data among studies. Having similar field and laboratory approaches are critical for comparable data to understand the extent and impact of PFAS across the watershed. Actions to improve comparability of data could include: (1) adoption of EPA draft Method 1633 (most recent version; EPA, 2022c) for PFAS analysis in water, tissue, and sediment samples to ensure similar number of analytes and detection limits; (2) adoption of consistent study designs and sampling methods; (3) identification of at least one sentinel or integrative species that can be sampled broadly across the Chesapeake Bay watershed (e.g., bass, a sensitive species with high economic importance); and (4) identification of a set of common assumptions/ approaches to build food web models. Consistency among test methods is vital to compare data across site, study area, and media. A recent review of PFAS in biosolids showed dramatically different concentrations for the same samples across laboratories/ institutions (Dickman and Aga, 2022), highlighting the need for method consistency and broader coordination. Consistency is also important in model development (e.g., source fingerprinting) and/or the use of predictive tools (e.g., identify overlap among vulnerable juvenile populations and likely fish harvest areas). **Developing field and analytical guidance that encourages consistency and data sharing directly supports SG1, SG2, and SG7. Identifying a sentinel or common species will help support gaps associated with SG4, SG5, SG6, and SG9.**

Collect standardized data to develop ecological risk assessments across a range of species for the protection of aquatic resources. This need involves: (1) prioritizing studies to address sublethal effects and the development of corresponding thresholds; (2) acute and chronic toxicity testing of PFAS mixtures; (3) development of aquatic life criteria for saline waters; and (4) identifying synergistic responses with other contaminants (e.g., PCBs, mercury, pesticides, etc.). **Developing PFAS thresholds across a range of species in support of risk assessments supports gaps identified in SG5 and SG9.**

We recognize that additional factors and priorities may exist beyond those identified in this report and by the workshop participants. This report reflects a broad effort to bring together knowledge from a range of science disciplines to describe the current state of the science of PFAS. Workshop participants shared knowledge of PFAS in the environment, its status, effects, the developing science, and policy needed to inform society of potential impacts to humans, and what research priorities could make the most of what is already known. Many of the science gaps identified here, though at times related, do not need to be pursued sequentially in order to successfully advance our understanding of PFAS in the Chesapeake Bay watershed. Multiple lines of study can be pursued simultaneously and coordinated across partners, jurisdictions, academia and government agencies.

The scientific and resulting policy landscape for PFAS is rapidly evolving, as evident during the time the STAC workshop inventory was conducted (appendix C) and release of this workshop report (e.g., updated health advisories, updated EPA method document). The current circumstance of numerous scientific gaps, common to many jurisdictions across the Chesapeake Bay Watershed, presents a unique opportunity to pool resources, streamline methods and approaches, and share findings. A well-integrated and timely response to the recommendations outlined in this workshop report, particularly those that include science gaps identified to need urgent attention, could benefit both current needs as well as future assessments at broader scales.

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Appendix A: Workshop Agenda

Chesapeake Bay Program's (CBP)
Scientific and Technical Advisory Committee (STAC)

Improve the Understanding & Coordination of Science Activities for PFAS in the Chesapeake Watershed
May 17-18, 2022

In person participation: Historic Inn of Annapolis
Workshop Webpage

DAY 1: Tuesday, May 17, 2022

9:15 am **Coffee & Light Breakfast (Provided)**

9:30 am **Welcome & Opening Comments** – *Kelly Smalling (USGS)*

***Session 1*: Current Understanding & Efforts to Address PFAS**

This session will provide an overview of what is known in the Chesapeake Bay watershed while highlighting PFAS studies in other large watersheds with the purpose of understanding other comparable national efforts that may be considered.

9:35 am **Assessing the Ecological Risks of PFAS: Overview of an International Workshop** –*Jeff Steevens (USGS)*
Jeff Steevens will provide a summary of PFAS effects and current understanding of potential effects.

10:00 am **Summary of Current Understanding & Overview of Inventory Response** – *Michelle Lorah (USGS)*
Michelle Lorah will present an overview of current understanding and analyses of sources, occurrence, and fate of PFAS in the Chesapeake, including a literature review of relevant research.

10:25 am **Quantifying the Risk Panel: Investigations into Other Watersheds**
This panel will examine what investigations in other watersheds have discovered about PFAS and its ecological burden on fish and wildlife.

- **Great Lakes** – *Brian Lenell (EPA Region 5)*
- **Delaware Basin** – *Ron MacGillivray (Delaware River Basin Commission)*
- **PFAS Occurrence and Concentrations in Puget Sound Aquatic Life** – *Louisa Harding (WA Dept of Fish and Wildlife)*

11:05 am **Break**

11:20 am **Q&A for Panelists**
Question and answer session with invited speakers from the 'Quantifying the Risk Panel'.

11:35 am **Large Group Discussion**
The Steering Committee will lead participants in a focused discussion on questions, gaps and research needs.

12:00 pm **Lunch (Provided)**

Session 2: Considerations for Establishing PFAS Thresholds: Consumption Advisories & Identifying Potential Effects on Aquatic Organisms

This session will provide information and discuss options for developing PFAS fish consumption advisories and provide information on studies designed to assess the potential effects of PFAS on aquatic organisms in the Chesapeake watershed.

1:00 pm **Components to Develop Chesapeake Fish Consumption Advisories**

A series of short talks discussing approaches to develop consumption advisories and tools to support their development.

- **1:00 pm PFAS and NJ Fish Consumption Advisories** – *Sandra Goodrow (NJDEP)*
- **1:20 pm An Integrative Modeling Approach to Support Consumption Advisories** – *Tom Ihde (Morgan State), Lee Blaney (UMBC)*
- **1:40 pm Tissue Sampling in Maryland** – *Amy Laliberte (MDE)*

2:00 pm **Studies of Potential Toxic Effects on Aquatic Organisms**

A series of talks exploring the species of most concern in the Bay and watershed.

- **2:00 pm Fish Plasma** – *Heather Walsh (USGS)*
- **2:20 pm PFAS Toxicity to Aquatic Animals** – *Jamie Suski (EA Engineering, Science and Technology, Inc.)*
- **2:40 pm Overview of SERDP PFAS Ecotox Projects** – *Hunter Anderson (US Air Force)*
- **3:00 pm Summary of NOAA/NCCOS Research on PFAS** – *Marie DeLorenzo (NOAA)*

3:20 pm **Break**

3:35 pm **Small Group Discussion**

Participants will split into breakouts both virtually and online. Discussion will focus on identifying gaps and research/monitoring priorities with an emphasis on development of consumption advisories and studies addressing effects on aquatic organisms.

4:15 pm **Report Outs & Large Group Discussion**

Participants will report out on identifying gaps (and actionable recommendations) that should be considered for research and coordinated monitoring related to ecotoxicology.

4:45 pm **Recess**

DAY 2: Wednesday, May 18, 2022

9:00 am **Coffee & Light Breakfast (Provided)**

9:15 am **Synthesis of Day 1 & Focus of Day 2 –** *Kelly Smalling (USGS)*

Kelly Smalling will provide opening comments, highlights and key takeaways from Day 1, and the focus of Day 2.

Session 3: Considerations for Developing a Coordinated Monitoring Effort for PFAS in the Chesapeake Bay: Sampling & Analysis

Currently, jurisdictions and researchers are independently making decisions about sampling and analysis methods. Appropriate selection, pros and cons (or benefits/drawbacks) of various methods in water and tissue are common questions. Coordinating these approaches now will support coordinated monitoring effort and allow for assessment of data at a broader scale.

9:30 am **Summarize Study Design & Method Information**

A series of talks summarizing existing methods currently being utilized by jurisdictions and researchers within the Chesapeake Bay and elsewhere.

- **9:30 am** Overview of Inventory — *Michelle Lorah (USGS)*

- Common Approaches Being Adopted
    - **9:40 am Tissue Methods** – *Anna Robuck (Mt Sinai School of Medicine)*
    - **10:00 am Water Sampling and Analysis** – *Joe Duris (USGS)*

10:30 am **Small Group Discussion**
Participants will split into breakouts both virtually and online. Discussion will focus on sampling and analysis methods.

11:10 am **Break**

11:20 am **Report Outs & Discussion**
Participants will report out on current methods being utilized and recommendations that support a coordinated monitoring effort and allow for assessment of data at a broader scale.

12:00 pm **Lunch (Provided)**

Session 4: Develop Recommendations to Address Science Gaps for a More Coordinated Research & Monitoring Effort for PFAS in the Chesapeake

This session will discuss options and develop actionable recommendations for research and coordinated monitoring of PFAS in the Chesapeake watershed.

1:00 pm **Small Group Instruction –** *Kelly Smalling (USGS)*

1:15 pm **Small Group Discussion**
Participants will discuss the high priority science gaps identified during Session 1 and 2 and develop actionable recommendations for a more coordinated monitoring of PFAS including an integrated and cost-effective approach for monitoring, modeling, and innovative methods across the watershed. There will be a built-in break participants will take in their groups.

2:45 pm **Break**

3:00 pm **Report Outs & Discussion**
Breakout groups will report out and then the entire group will work to identify and discuss recommendations for research and monitoring.

3:45 pm **Wrap Up, Next Steps & Closing Comments**

4:00 pm **Adjourn**

4:00 pm **Steering Committee Meets**
After the workshop adjourns, the Steering Committee will meet to discuss workshop takeaways, next steps, and a timeline for writing the STAC report.

Appendix B: Workshop Participants

Name	Affiliation
Amy Laliberte	Maryland Department of the Environment (MDE)
Amy McMullen	Pennsylvania Department of Environmental Protection (PA DEP)
Ann Swanson	Chesapeake Bay Commission
Anna Robuck	Icahn School of Medicine at Mount Sinai
Bel Martinez da Matta	MDE
Betsy Nicholas	Waterkeepers Chesapeake
Brent Walls	Potomac Riverkeeper Network
Brian Barone	District of Columbia Department of Energy and the Environment (DOEE)
Brian Lenell	U.S Environmental Protection Agency (EPA)
Bryant Thomas	Virginia Department of Environmental Quality (VA DEQ)
Carissa Moncavage	EPA Region 3
Christina Davis	Potomac Riverkeeper Network
Dennis Low	PA DEP
Doug Austin	Chesapeake Bay Preservation Ordinance
Dr. Sinisa Urban	Maryland Department of Health
Efeturi Oghenekaro	DC DOEE
Emerson Christie	Washington Department of Health
Emily Woodward	U.S. Geological Survey (USGS)
Erin Letavic	Herbert, Rowland & Grubic, Inc.
Fred Pinkney	U.S. Fish and Wildlife Service (FWS)
Greg Allen	EPA
Haydee De Clippeleir	District of Columbia Water
Heather Preisendanz	Pennsylvania University (PSU)
Heather Smiles	Pennsylvania Fish and boat
Heather Walsh	USGS
Heidi Moltz	Interstate Commission on the Potomac River Basis (ICPRB)
Hilary Swartwood,	Chesapeake Bay Program (CBP)
Hunter Anderson	U.S. Air Force
Jamie Suski	EA Engineering, Science and Technology, Inc., PBC
Jeff Steevens	USGS
Jennifer Starr	Local Government Advisory Committee-Chesapeake Bay
Jeremy Hanson	Chesapeake Research Consortium (CRC)
Joe Duris	USGS
John Cargill	Department of Natural Resources and Environmental Control
Kacie Camp	EA Engineering, Science, and Technology
Kang Xia	Virginia Tech
Karl Berger	Metropolitan Washington Council of Governments
Kathy Boomer	Foundation for Food and Agricultural Research
Ke He	University of Maryland, Baltimore Country (UMBC)
Kevin Richards	Washington Department of Fish and Wildlife (WDFW)
Kofi Asante-Duah	District of Columbia Government
Lee Blaney	UMBC
Lee Currey	MDE
Len Schugam	MDE
Leonard Schugam	MDE
Lisa Emili	PSU
Louisa Harding	WDFW
Lucretia Brown	DC DOEE
Mahsa Modiri Gharehveran	EA Engineering, Science, and Technology
Marie DeLorenzo	National Oceanic and Atmospheric Administration (NOAA)
Mark Cantwell	EPA
Mark Mank	MDE
Matthew Kundrat	PA DEP
Mi-Ling Li Li	University of Delaware (Udel)
Michael Bott	Delaware
Michael Mashtare	PSU
Michelle Lorah	USGS
Molly Shuman-Goodier	WDFW
Natalie Karouna-Renier	USGS
Phillip Musegaas	Potomac Riverkeeper Network
Renee Bourassa	ICPRB
Ron McGillivray	Delaware River Basin Commission (DRBC)
Sadie Drescher	Chesapeake Bay Foundation (CBF)

Sandra Goodrow	New Jersey Department of Environmental Protection (NJDEP)	Tish Robertson	VA DEQ
Sara Breitmeyer	USGS	Todd Keyser	Delaware Department of Natural Resources (DE DNR)
Scott Knoche	Morgan State University	Tom Ihde	Morgan State University
Scott Phillips	USGS	Trevor Needham	USGS
Sherry Witt	General Dynamics Information Technology	Zack Hopkins	USGS
Steven Chow	Johns Hopkins University		

Appendix C: Pre-workshop materials and inventory

Inventory Summary

Delaware

1. Delaware Department of Natural Resources and Environmental Control

   Current goal of PFAS program is discovery/occurrence characterization. Larger potential sources have been identified, but occurrence and distribution efforts continue. Some targeted sampling is occurring, and plans are being developed to expand sampling as funding permits.
   Sampling drinking water mostly.
   Started adding PFAS to fish monitoring of largemouth bass (added to a mercury study).

2. New Castle County, Delaware

   In 2019, the Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) conducted an exposure assessment (EA) from in and around the City of New Castle in New Castle County, Delaware, near New Castle Air National Guard Base.

   https://www.atsdr.cdc.gov/pfas/activities/assessments/sites/new-castle-county-de.html?CDC_AA_refVal=https%3A%2F%2F

   www.atsdr.cdc.gov%2Fpfas%2Fcommunities%2FNew-Castle-County-DE.html

   https://www.atsdr.cdc.gov/pfas/communities/factsheet/New-Castle-County-Community-Level-Results-Factsheet.html

3. Blades, Delaware

   Superfund site that is in the Chesapeake Bay watershed. The Delaware Department of Natural Resources and Environmental Control (DNREC) worked with the EPA to evaluate PFAS in the Town of Blades drinking water wells because of a history of manufacturing processes that have operated in the area. After elevated PFAS was first detected in groundwater samples collected from three Blades municipal supply wells in 2018, additional private well sampling and investigation of potential source area was conducted. On Sept. 1, 2020, the U.S. Environmental Protection Agency (EPA) announced the addition of the Blades Groundwater Site to the Superfund National Priorities List (NPL).
   https://pfasproject.com/blades-delaware/

https://dnrec.alpha.delaware.gov/waste-hazardous/remediation/blades-groundwater-site/

Washington, D.C.

1. Department of Energy & Environment (DOEE)

   Current goal of PFAS program is discovery/occurrence characterization.
   Most work has focused on drinking water in collaboration with District of Columbia Water (DC Water).
   Recently began including PFAS as part of fish studies.
   Studying PFAS from the human health component in relation to service ware within the restaurant industry.

2. Sierra Club (Nonprofit)

   Sierra Club and Ecology Center tested commercially available home fertilizers consisting of biosolids for PFAS (33 target compounds and TOP assay). Reported that eight of the nine products exceeded screening limits for PFOS or PFOA set by Maine as a screening standard set for land application. Samples of Cured Bloom Soil Conditioner (Washington, D.C., Blue Plains Advanced Wastewater Treatment Plant, 100 percent biosolids) had the highest measured PFAS.
   Sludge in the Garden: Toxic PFAS in home fertilizers made from sewage sludge (sierraclub.org)

Maryland

1. Maryland Department of Environment (MDE); and Maryland Department of Health (MDH)- Occurrence in drinking water

   Current goal of PFAS monitoring program is for discovery/occurrence characterization particularly as related to drinking water sources.

   MDE has initiated an assessment of the occurrence of PFAS in drinking water from 137 selected community water systems (CWS) water treatment plants (WTPs), starting September 2020.
   Study results may trigger the need for additional finished water sampling, monitoring of raw water sources, and other actions. Levels of PFOA+PFOS greater than the EPA's HAL of 70 ppt were found in samples collected from two CWS-WTPs that withdraw and treat groundwater from an unconfined aquifer.

   Link to Phase 1 Public Water System Study approach and report:
   Phase 1 Report_PFAS in Maryland's Public Drinking Water Sources
   https://mde.maryland.gov/programs/Water/water_supply/Documents/PFAS_PWSPFAS_Study_Factsheet.pdf

   A PFAS science roundtable sponsored by University of Maryland Center for Environmental Sciences (UMCES) in coordination with MDE was held on October 5, 2020, with over 20 scientists and PFAS experts from academia, federal agencies and the states of Pennsylvania and Delaware. Summary of Maryland's PFAS Scientific Roundtable

2. Maryland Department of Environment (MDE) - Source evaluation

Completed a desktop mapping exercise to set priorities for monitoring using available information on industries and facilities that are more likely to be PFAS sources (e.g., firefighting, certain metal finishing industries, DoD facilities) and proximity to certain drinking water source water that is more vulnerable (unconfined and semi-confined aquifers) or surface waters. Focused on targeting locations that may have the highest relative risk of human exposures. This source evaluation was used to guide sample collection for Phase 1 Report_PFAS in Maryland's Public Drinking Water Sources.

Currently seeking information on WWTPs to better understand those as possible sources of release either to water (effluent) or to land (biosolids) and on facilities with industrial stormwater discharge permits.

Targeted source studies:
St. Mary's oyster study - MDE in cooperation with Maryland's Department of Natural Resources (DNR) launched a pilot study to assess whether surface water and oysters in portions of the St. Mary's River and its tributaries near Naval Air Station (NAS) Patuxent River's Webster Field Annex have PFAS, but levels of concern were not found.
Link to information on St. Mary's pilot study measuring PFAS concentrations in oyster tissue and surface water:
https://mde.maryland.gov/programs/Water/FishandShellfish/Pages/StMarys_PFAS.aspx

Piscataway Creek Study - MDE in cooperation with DNR conducted surface water and fish sampling annually starting in 2020 to investigate foam release with both Joint Base Andrews and a fire-fighting training area as potential sources. Resulted in first fish consumption advisories in Maryland.
Piscataway Creek (Tidal and Non-Tidal) PFAS Study (maryland.gov)

3. Department of Defense (DoD) Sites

The report from the PFAS science roundtable sponsored by UMCES in coordination with MDE, held October 5, 2020, has a summary of military facilities in Maryland and status of DoD investigations.
Summary of Maryland's PFAS Scientific Roundtable

https://www.civilianexposure.org/report-shows-15-military-bases-in-maryland-contaminated-with-pfas/#:~:text=In%20March%2C%202018%20the%20DOD%20released%20a%20report%2C,using%20aqueous%20film-forming%20foam%20in%20routine%20fire-fighting%20exercises

4. National Oceanic and Atmospheric Administration (NOAA)

Chesapeake Bay, Maryland, and Charleston Bay, South Carolina

NOAA's National Status and Trends (NS&T) Mussel Watch Program conducted regional pilot studies to assess the magnitude and distribution of contaminants of emerging concern (CEC) in shellfish and sediment from different coastal zones. Oyster tissue and surficial sediment samples collected in 2015 in the Chesapeake Bay, Maryland, and Charleston Harbor, South Carolina, were analyzed for PFAS.

https://repository.library.noaa.gov/view/noaa/20268 - pdf available

https://coastalscience.noaa.gov/project/mussel-watch-program-assessment-chesapeake-bay-charleston-harbor/

5. U.S. Geological Survey (USGS)

   USGS fish tissue studies - Fish plasma samples from two sites in the Potomac River and two in the Susquehanna River drainage basins, differing in land-use characteristics, were analyzed for PFAS: IJERPH | Free Full-Text | Perfluoroalkyl Substances in Plasma of Smallmouth Bass from the Chesapeake Bay Watershed (mdpi.com)

   'Forever chemicals' found in Chesapeake region's freshwater fish | Fisheries | bayjournal.com

   USGS Maryland-Delaware-District of Columbia Water Science Center in collaboration with University of Maryland Baltimore County and MDE are studying PFAS occurrence in Maryland wet ponds. One-time sampling conducted of sediment in wet ponds used for stormwater management and analyzed for PFAS, PCBs, and metals. Data analysis ongoing.

   USGS Maryland-Delaware- District of Columbia Water Science Center is leading an ongoing study to look at PFAS in wastewater treatment plants in Patapsco and Potomac River watersheds. Data collection is currently ongoing.

Pennsylvania

1. USGS, Pennsylvania Department of Environmental Protection (PADEP), and Susquehanna River Basin Commission- Monitoring

   Current goals of PFAS program include data collection in surface water and fish tissue to characterize PFAS in Pennsylvania surface waters, to provide information for the development of surface water criteria, and to inform permitted activities. A sampling plan was developed based on identifying potential sources of PFAS contamination (PSOC) and sampling from public water systems that had one or more sources within 0.5 mile of a PSOC. In addition, source evaluation efforts have targeted the Neshaminy Creek basin with surface water data collection.
   Pennsylvania Department of Environmental Protection Bureau of Safe Drinking Water PFAS Sampling Plan (state.pa.us)
   The USGS PAWSC collaborated with the PADEP and the Susquehanna River Basin Commission to collect 216 surface-water samples in a single month in September 2019. A USGS data release includes PFAS & associated quality-control (QC) data from integrated, discrete surface-water samples from 178 PADEP Surface Water Quality Network (WQN) sites and 36 QC samples. Developed PFAS sampling techniques to allow for low-level detections. Tested discrete and passive sampling methods. Potential point sources were identified by PADEP as part of the PFAS sampling plan to prioritize sites for PFAS sampling to generate statewide occurrence data.
   Based on the results of the 2019 effort, data collection is occurring monthly at a subset of sites. In addition, 50 fish tissue samples have been analyzed. Yearly fish tissue and monthly surface water data collection is planned to continue.
   https://www.usgs.gov/news/usgs-releases-first-its-kind-survey-pfas-pennsylvania-surface-waters

https://www.sciencebase.gov/catalog/item/5e4d5e72e4b0ff554f6d146b

Pennsylvania Statewide Surface Water-Quality Monitoring Network - Per- and polyfluoroalkyl Substances Sampling Preparation | U.S. Geological Survey (usgs.gov)
PFAS Surface Water Discrete and Passive Samples: 2019 (state.pa.us)
Trigger levels for contaminant concentrations found in fish tissue and tiered meal advice exists for PFOS in Pennsylvania (see page 2-80 of DEP Assessment Methodology for Stream and Rivers 2021): ASSESSMENT_BOOK_2021.pdf (state.pa.us)

Do Not Eat advisory for all fish species within the Neshaminy Creek basin: Article Viewer (pa.gov)

2. Pennsylvania Department of Health (PDH) and Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR)

   The Agency for Toxic Substances and Disease Registry (ATSDR) is evaluating per- and polyfluoroalkyl substances (PFAS) levels in drinking water and related public health concerns near military bases in Bucks and Montgomery Counties, Pennsylvania. Firefighting foam that contained PFAS was used at these bases in the past. ATSDR evaluated PFAS levels in drinking water and the possibility of health effects from exposure. Executive summaries give details about ATSDR's evaluation of PFAS in drinking water near the former Naval Air Warfare Center located in Warminster Township, Bucks County, Pennsylvania (Warminster site) and the former Naval Air Station Joint Reserve Base (NASJRB) and the active Air Reserve Station (ARS) Willow Grove located in Horsham, Montgomery County (Willow Grove site).

   PEATT Pilot Project Final Report April 29 2019.pdf (pa.gov)

   https://www.atsdr.cdc.gov/HAC/pha/willowgrove/Evaluation_of_PFAS_in_Drinking_Water_FS-508.pdf

   https://www.atsdr.cdc.gov/HAC/pha/NavalAirWarfareCenter/Naval_Air_Warfare_Center_LHC_01-20-2016_508.pdf

3. Department of the Navy, Naval Support Activity (NSA) Mechanicsburg

   In January and February 2022, the Department of the Navy conducted an off-installation drinking water investigation near Naval Support Activity (NSA) Mechanicsburg for PFAS. Tested eight drinking water wells, and concentrations were found to be below the U.S. EPA Lifetime Drinking Water Health Advisory level for PFOA and PFOS.

   https://www.navfac.navy.mil/products_and_services/ev/products_and_services/env_restoration/installation_map/navfac_atlantic/midlant/mechanicsburg/mechanicsburg_pfas.html

Virginia

1. Virginia Department of Environmental Quality (DEQ) and the Virginia Department of Health (VDH)

   The goals of statewide monitoring are focused on human health with objectives to understand 1) the prevalence of PFAS in surface waters by sampling probabilistic sites and sites located downstream of suspected sources, and 2) the temporal dynamics of PFAS by conducting repeated sampling at several long-term monitoring sites.

Chickahominy River PFAS Study is being conducted to 1) verify a locality's initial findings that PFAS concentrations in source waters are elevated in the Middle Chickahominy River watershed and 2) collect environmental and drinking water data to understand the human exposure of PFAS in the Middle Chickahominy River watershed.
Elevated PFAS Levels Found in the Chickahominy River Watershed - Newsroom (virginia.gov)

For drinking water, the 2016 EPA health advisories for PFOA and PFOS are being used to communicate risk. Risk-based screening values for environmental data (surface water and fish tissue) have been developed for the purposes of informing management decisions in a specific watershed. Target constituents are ones for which EPA has published finalized toxicity assessments: PFOA, PFOS, PFBS, and Gen X.

2. Virginia Department of Environmental Quality (DEQ) – Source evaluation and sites

   Potential sources have been identified using desktop analysis of Standard Industrial Classification codes. These include industrial dischargers and publicly owned treatment works receiving wastewater from industries that potentially use PFAS. The state National Pollution Discharge Elimination System (NPDES) program is developing a survey for distribution to the identified facilities to better understand current and/or historical activities and processes that may be possible sources of PFAS.

   The following areas have been identified as PFAS sites in Virginia: Fentress Air Base (Fentress), Oceana Naval Air Station (Virginia Beach), Northwest Annex (Chesapeake), NASA Wallops Island, and DuPont Spruance (Richmond).

   Oceana Naval Air Station- The Navy initially sampled private drinking water wells in 2016 for PFOA and PFOS, and all were below the EPA's health advisory level for PFOS and PFOA.

   https://www.cnic.navy.mil/content/dam/cnic/cnrma/pdfs/Environmental/Drinking_Water_and_Testing_Information/Installation_Scheduling_and_Results/Oceana/Oceana%20Factsheet_Sep2018_09212018.pdf

   https://www.cnic.navy.mil/content/dam/cnic/cnrma/pdfs/Environmental/Drinking_Water_and_Testing_Information/Installation_Scheduling_and_Results/Oceana/NAS_Oceana_Basewide_PFAS_SI_Report_final.pdf

   Wallops Island-
   Since 2016, NASA has routinely conducted testing of the facility's groundwater monitoring wells and drinking water wells and the Town of Chincoteague's drinking water wells for the presence of PFAS.
   https://www.nasa.gov/feature/background-latest-information-on-pfas-at-nasa-wallops/

West Virginia

1. West Virginia Department of Environmental Protection and Department of Health and Human Resources

Current PFAS program is designed to aid in the identification of the potential sources of contamination and to focus on drinking water effects. The two main contamination sources known in West Virginia are the Chemours site and surrounding area and the Air Guard Base in Martinsburg area.

Sampled source water for all public drinking water systems with USGS conducting the sampling (Senate Concurrent Resolution 46 (SRC 46), Feb. 2020).

2. USGS Virginia and West Virginia Water Science Center

   USGS is completing a study by June 2022 for the West Virginia Department of Environmental Protection to provide a PFAS public source-water supply study plan. The purpose is to inform state regulatory agencies about the distribution of PFAS contamination and potential PFAS contamination in public drinking water sources using data of known quality. Specific objectives of the PFAS public source-water supply study plan include: (1) Identifying the drinking water supplies in West Virginia that have measurable amounts of PFOS, PFOA, and related PFAS compounds in their raw source-water; (2) Determining if there are geochemical, watershed, industrial use, land use, or geohydrologic factors or processes that affect the presence of these compounds in public source-water supplies; (3) Informing state agencies and the public of any need for additional PFAS investigation, such as sampling of domestic wells; and (4) Assisting state regulatory agencies in protecting public health by providing risk-based information on statewide PFAS distribution in source water

3. Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR)- Berkeley County

   The Shepherd Field Air National Guard Base previously used aqueous film-forming foam containing PFAS to fight fires and train workers. PFAS transport in groundwater to off-site likely affected the City of Martinsburg's Big Springs well, which supplies drinking water to City of Martinsburg and a small percentage of Berkeley County customers.
   https://www.atsdr.cdc.gov/pfas/docs/factsheet/Berkeley-County-WV-Site-Factsheet-508.pdf

   https://www.atsdr.cdc.gov/pfas/activities/assessments/sites/berkeley-county-wv.html?CDC_AA_refVal=https%3A%2F%2Fwww.atsdr.cdc.gov%2Fpfas%2Fcommunities%2FBerkeley-County-WV.html

Other Resources, Agencies, and Organizations

Federal Agencies

FACT SHEET: Biden-Harris Administration Launches Plan to Combat PFAS Pollution | The White House

U.S. federal agencies conducting research on PFAS include EPA, DoD, USDA, HHS (National Institutes of Health, National Institute of Environmental Health Sciences), ATSDR, CDC, and U.S. Food and Drug

Administration, U.S. Geological Survey, U.S. Department of Transportation, Department of Homeland Security, and the U.S. Department of Commerce (National Institute of Standards and Technology).

Environmental Protection Agency:

EPA PFAS Plan: PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024

Draft Method 1633: CWA Analytical Methods for Per- and Polyfluorinated Alkyl Substances (PFAS)

Draft Method 1621: Adsorbable Organic Fluorine: Draft Method 1621-AOF

NPDES memo, Addressing PFAS Discharges in EPA-Issued NPDES Permits and Expectations Where EPA is the Pretreatment Control Authority: Industrial Wastewater

Proposed aquatic life criteria for PFOA and PFOS, released May 3, 2022; open for public comment and any new toxicity data:

Aquatic Life Criteria - Perfluorooctanoic Acid (PFOA)

Aquatic Life Criteria - Perfluorooctane Sulfonate (PFOS)

EPA uses the Unregulated Contaminant Monitoring Rule (UCMR) to collect data for contaminants suspected to be present in drinking water, but that do not have regulatory standards set under the Safe Drinking Water Act (SDWA). Monitoring results include PFAS.

https://www.epa.gov/dwucmr/occurrence-data-unregulated-contaminant-monitoring-rule#3

https://www.epa.gov/sites/default/files/2017-02/documents/ucmr3-data-summary-january-2017.pdf

U.S. Department of Defense

https://www.defense.gov/Spotlights/pfas/

PFAS Task Force Progress Report March 2020 (defense.gov)
https://www.ucsusa.org/sites/default/files/attach/2018/09/a-toxic-threat-pfs-military-fact-sheet-ucs-2018.pdf

FY18 HASC Brief on PFOS-PFOA (partner-mco-archive.s3.amazonaws.com)

DoD’s Environmental Research Programs: Environmental Restoration (serdp-estcp.org)

U.S. Geological Survey

PFAS program includes site-specific, regional, and national scale studies of PFAS occurrence and controls on distribution and research studies of fate, transport, and ecosystem/toxicity effects, as well as development of remediation technologies.

Integrated Science for the Study of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) in the Environment—A Strategic Science Vision for the U.S. Geological Survey:
https://pubs.er.usgs.gov/publication/cir1490

Per-and Polyfluoroalkyl Substances (PFAS) Integrated Science Team | U.S. Geological Survey (usgs.gov)

National Institute of Environmental Health Sciences

Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) (nih.gov)

US Food & Drug Administration

Per- and Polyfluoroalkyl Substances (PFAS) | FDA

CDC and ATSDR

Learn about PFAS | ATSDR (cdc.gov)

NOAA's National Centers for Coastal Ocean Science

Goal is to deliver applied science products and services and monitoring data that elucidate the fate, transport, and toxicity of PFAS in coastal ecosystems to support effective regulatory decisions and safe use of PFAS and new alternative compounds. PFAS work has been directly driven by specific partnerships with DoD, EPA, and National Institute of Standard and Technology (NIST), and primarily focused on toxicity studies in the lab. Conducted (or plan to conduct) monitoring in tidal creeks of South Carolina and Great Lakes region through the NOAA Mussel Watch Program; a 2015 study included Chesapeake Bay (see Maryland section above). Mussel Watch Program efforts in the Great Lakes are using metabolomics as indicators of PFAS exposure and stress in benthic organisms/bivalves/fish. Combining these data with land use, hydrology, and other oceanographic data can contribute to source tracking.

NOAA Mussel Watch Program: An Assessment of Contaminants of Emerging Concern in Chesapeake Bay, MD, and Charleston Harbor, SC - NCCOS Coastal Science Website

National Institute of Standards and Technology

PFAS reference materials and interlaboratory studies.
Measurement Science of Per- and Polyfluoroalkyl Substances (PFAS) | NIST
NIST-PFAS Program Overview | NIST

Multi-Agency

Interstate Technology and Regulatory Council (ITRC) online document, references, and training:
PFAS — Per- and Polyfluoroalkyl Substances (itrcweb.org)

ECOS-
Environmental Council of the States (ECOS) began compilation of information on state PFAS standards, advisories, and guidance values in 2019 and updated most recently in March 2022. Plan to update annually.

https://www.ecos.org/wp-content/uploads/2022/03/Standards-White-Paper_Updated_V3_2022_Final.pdf

Nonprofit

Environmental Working Group:
PFAS Chemicals | Environmental Working Group (ewg.org)
Interactive Map: PFAS Contamination Crisis: New Data Show 2,854 Sites in 50 States (ewg.org)
Interactive Map: Suspected industrial discharges of PFAS (ewg.org)
Interactive Map: 679 Military Sites With Known or Suspected Discharges of PFAS (ewg.org)
Northeastern University:
The PFAS Project Lab – Studying Social, Scientific, and Political Factors of Per- and Polyfluoroalkyl Substances
An *interactive map* that brings together information about known and suspected PFAS contamination sites across the United States: PFAS Sites and Community Resources – The PFAS Project Lab

Green Science Policy Institute:
Team of science and policy experts collaborates with scientists, business and government decision makers, and NGOs. PFAS - Green Science Policy Institute
PFAS Solutions:
Launched in 2019 by the Science, Technology & Research Institute of Delaware (STRIDE), a Delaware not-for-profit corporation. Laboratory in New Castle, Delaware.
PFAS Solutions - Quality Science and Information (pfasolutions.org)

Academia

University of Maryland Baltimore County (Lee Blaney) – PFAS research on environmental occurrence and distribution, treatment and remediation processes, and passive sampling methods.
Johns Hopkins University (Carsten Prasse) - Occurrence of PFAS in biosolids and their fate after land application including plant uptake. Additional research on treatment strategies to remove PFAS from contaminated groundwater.
Morgan State (Tom Ihde) - Estimation of biomagnified concentrations of PFAS spatially, throughout the Chesapeake Bay. Currently conducting a pilot study in collaboration with University of Maryland Baltimore County focused on developing a new modeling approach to support consumption advisories. The initial focus of this work is quantification of contaminant levels in blue crab; future studies are planned for striped bass and blue catfish.
Penn State University (Heather Preisendanz; Raymond Najjar) – PFAS research on environmental occurrence and distribution, potential sources, fate and transport; field-based studies to look at impacts of agricultural sources of PFAS (biosolids and wastewater irrigation) on groundwater quality.

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Glossary

Aqueous film forming foam (AFFF). A highly effective type of fire suppressant agent, intended for use for high-hazard liquid hydrocarbon fires, and containing fluorinated organic compounds. Defining feature of AFFF is that the solution produces an aqueous film that spreads across the surface of a hydrocarbon fuel to extinguish the flame and to form a vapor barrier between the fuel and atmospheric oxygen to prevent re-ignition.

Bioaccumulation/Biomagnification. Toxins can accumulate over time when organisms absorb the toxin from the environment (bioaccumulation). A predator that consumes multiple organisms that have bioaccumulated the toxin magnifies the amount of that toxin in its own body; the process of magnification continues up the food chain (biomagnification). The result of biomagnification is that the highest concentrations of the toxin are found in the tissues of apex predators.

PFAS. No universally accepted definition of PFAS. This term is used to describe all per- and polyfluoroalkyl substances, and broadly encompasses the more than 4,000 compounds known to exist within the PFAS class. In general, PFAS are characterized as having carbon atoms linked to each other and bonded to fluorine atoms at most or all of the available carbon bonding sites.

PFAAs. This term refers to perfluoroalkyl acids such as perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA), which are two of the most widely recognized PFAAs and the subject of current EPA drinking-water health advisories. PFAAs are fully fluorinated (that is, there is no hydrogen attached to carbon in the carbon chain). Although there are several PFAA structures, references to PFAAs in this document refer specifically to perfluoroalkyl carboxylates (such as PFOA) and (or) perfluoroalkyl sulfonates (such as PFOS), which have been the primary subject of research on PFAS and are measured in routine laboratory analysis. PFAAs are frequently referred to as "legacy" or "terminal" PFAAs because of their long history of use, their resistance to transformation into another compound, and their persistence in the environment.

Perfluoroalkyl substances. Fully fluorinated alkane (carbon chain) molecule. They have a chain (tail) of two or more carbons atoms with a charged functional group (head) attached at one end.

Polyfluoroalkyl substances. Partially fluorinated. The molecule has a nonfluorine atom (typically hydrogen or oxygen) attached to at least one, but not all, carbon atoms, while at least two or more of the remaining carbon atoms in the carbon chain tail are fully fluorinated. Some polyfluoroalkyl substances can break down in the environment to form terminal PFAAs and are referred to as PFAA precursors.

Surfactant. A surface-active agent that lowers the surface tension of a liquid.

Tail. The part of a molecule that is a chain of two or more carbon atoms.

Zwitterion. An ionic compound containing both positively and negatively charged groups with a net charge of zero.

Glossary adapted from:

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