While regulations continue to unfold, industries across the country are preparing to deal with the identification and remediation of per- and polyfluoroalkyl substances (PFAS) in soil, groundwater and surface water. Private industry, government organizations and the military are seeking out smart, proven processes to help tackle this challenging issue.
Per- and polyfluoroalkyl substances (PFAS) comprise a suite of manmade compounds used across multiple industries. While PFAS have been widely phased out of production, their historical use has resulted in the contamination of soil, groundwater and surface water bodies, potentially creating environmental liabilities for entities that used, transported and/or disposed of PFAS. Unlike other compounds that naturally degrade in the environment and have relatively short half-lives in ecological and human receptors, PFAS persist as nonbiodegradable compounds that are potentially bioaccumulative and toxic. The chemical properties of PFAS make these compounds challenging to remediate in situ and difficult and costly to remove using traditional treatment and remediation technologies (Vecitis, et al, 2009).

Two PFAS compounds that have been the subject of particular regulatory focus are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). PFOS and PFOA are nonbiodegradable, chemically stable and bioaccumulative (Agency for Toxic Substances and Disease Registry [ATSDR], 2015, and Association of State and Territorial Solid Waste Management Officials [ASTSWMO], 2015). PFOS and PFOA have been on the environmental industry’s radar for decades and were the subject of major environmental settlements in the 1990s and 2000s. However, recent U.S. Environmental Protection Agency (USEPA) actions regarding PFOS and PFOA — including the 2009 provisional health advisory for PFOA and PFOS (USEPA, 2009) and the more recent establishment of the 2016 lifetime health advisory levels (USEPA, 2016a) — have resulted in a new set of environmental challenges for entities that handled and/or used PFAS.

**HOW WE GOT HERE**

While the PFAS family includes thousands of individual compounds, USEPA and state regulatory agencies have primarily focused on long-chained perfluoroalkyl acids (PFAAs) because of these compounds’ toxicity, stability in the environment and potential to bioaccumulate. PFAAs include perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkane sulfonates (PFSAs). Both PFCAs and PFSAs are fluorinated hydrocarbons of variable carbon-chain lengths and can be distinguished from one another by the sulfonic and carboxylic functional group present. The two PFAS that have been studied most include PFOA, of the PFCA group, and PFOS, of the PFSA group. PFOA and PFOS saw an increase in production over the last half-century and are the stable degradation products of other PFCAs and PFSAs and related compounds.

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**Per-fluorinated Compounds**

- Perfluoroalkyl Acids (PFAAs)
  - Perfluorobutanoic acid (PFBA)
  - Perfluoroheptanoic acid (PFHpA)
  - Perfluorooctanoic acid (PFOA)
  - Perfluorodecanoic acid (PFDoA)
- Perfluorocarboxylic Acids (PFCAs)
  - Perfluorobutanoic acid (PFBA)
  - Perfluoroheptanoic acid (PFHpA)
  - Perfluorooctanoic acid (PFOA)
  - Perfluorodecanoic acid (PFDoA)
  - Perfluorododecanoic acid (PFDoA)
- Perfluoroalkane Sulfonates (PFSAs)
  - Perfluorobutane sulfonate (PFBuS)
  - Perfluoroheptane sulfonate (PFHpS)
  - Perfluorooctane sulfonate (PFOS)
  - Perfluorodecanoic acid (PFDS)
  - Perfluoroundecanoic acid (PFUA)
  - Perfluorododecanoic acid (PFDoA)

**Poly-fluorinated Compounds**

- > 6,000 compounds including:
  - Fluorotelomer alcohols
  - Sulfonamido carboxylates
  - Fluorotelomer betaines
  - Sulfanomidoethanol
  - Fluorotelomers
  - Sulfanomide ketones, aldehydes and ethers
  - And more
  - *INCLUDES PERFLUORINATED PRECURSORS*

Note: Diagram presents common compounds and chemical groups and may not be complete.
PFOA is a fluorosurfactant that has been manufactured in the United States since the 1940s. In the early 2000s, manufacturers began phasing out PFOA production because of the USEPA’s concerns about health effects related to its use and presence in the environment (USEPA, 2016d). PFOA was a primary ingredient in Teflon; was used to treat textiles, paper and other surfaces to impart water-, oil- and fire-resistant properties; and is present in electronic devices and firefighting foams. While no longer widely used in these applications, PFOA does form as an unintended byproduct during the synthesis of other fluorotelomeres. As a result, PFOA can be present at low concentration in finished products containing or treated with fluorotelomeres. PFOS was manufactured in the U.S. beginning in 1949 and was phased out of production in 2000; it is still produced in some other countries. Its primary uses have included fabric protection agents and electronics; as an ingredient in cleaners, waxes, and other household and commercial products; in the treatment of metal surfaces; in hydraulic fluids used in commercial aviation; and in the production of Aqueous Film Forming Foam (AFFF).

REGULATORY STATUS
In May 2016, the USEPA established a lifetime health advisory of 70 parts per trillion (ppt) for PFOA and PFOS (USEPA, 2016a). In instances where both compounds are present, the combined concentration of PFOA and PFOS must not exceed 70 ppt. This lifetime health advisory was established using the results of lab studies and was informed by epidemiological studies. It is generally considered protective of at-risk populations, although more recent studies have suggested even lower drinking water standards are needed to provide protection.

While the 2016 lifetime health advisory has served as the most sweeping guidance concerning PFAS in the U.S., both drinking water and groundwater standards have been established by various state regulatory agencies, with new and updated standards frequently being issued (ASTSWMO, 2015). These new drinking water standards have resulted in legal action from individuals and entities with affected drinking water sources against industry sectors and the U.S. Department of Defense. These lawsuits commonly cast a broad net and levee grievances against multiple respondents located along affected waterways and drinking water resources.

POTENTIAL HEALTH IMPACTS
Given the widespread historical use of PFAS, approximately 95 percent or more of the general population is estimated to have been exposed to PFOA and PFOS (ATSDR, 2015). Exposure to PFOA and PFOS may have occurred through exposure to air, indoor dust, food, water and various consumer products. Ingestion of contaminated food and/or water is considered the most common route of exposure. Health effects resulting from exposure to PFOA and PFOS over certain concentrations may include developmental

MANAGEMENT OF PFAS LIABILITIES
Approaches to identifying and mitigating the risks and liabilities associated with PFAS contamination require careful planning and execution of both investigation and remediation:

- **Site assessment**: Our long-term understanding of the industries affected by PFAS contamination allows us to focus field investigations on potential release and source areas, reducing the time and cost required for field investigation efforts.

- **Adaptable approaches**: We implement field investigation and remediation studies using both traditional and innovative techniques to accurately evaluate PFAS impacts and remediation techniques under a variety of site settings and subsurface conditions.

- **Knowing your site**: Through the development of complex and defensible conceptual site models, our team is able to present site conditions to owners and stakeholders in understandable terms.

- **Remedial success**: By tracking technological advancements across the industry, we are able to select the most appropriate remedial approach that delivers the right solution for our clients’ success.
abnormalities for fetuses and infants; cancer (testicular, kidney); liver damage; and immune system and thyroid effects. However, it has been difficult to discern direct links between PFOA/PFOS exposure and specific diseases in human populations.

PFAS IN THE ENVIRONMENT
PFOA and PFOS are commonly found in soil, groundwater and surface water in locations surrounding their historic use, manufacturing, storage and disposal. This includes factories, metal plating operations, chemical manufacturing plants, transportation facilities and yards, and landfills where PFAS-containing wastes have been disposed. PFAS are also found where PFAS-containing products, such as fabric/textile conditioners or AFFF, were used or stored. In the aviation industry, PFAS are found in association with almost every firefighting training area, calibration area, deluge area, hot crash site and other areas where AFFF was used.

Another source of PFOA and PFOS in the environment is the degradation of precursor compounds (ATSDR, 2015). Common release mechanisms for PFAS include aerial deposition of stack emissions, direct application of PFAS-containing products, and incidental releases. Once released, chemical and biological processes will cause certain PFAS to degrade to PFOA and PFOS. When present in the environment, PFAS are readily soluble in water and have limited affinity for adsorption to soil. PFOA and PFOS exist as ions when present in groundwater and tend to form long and persistent groundwater plumes. The persistence of these compounds and their ability to be transported great distances makes them a serious threat to drinking water resources.

INVESTIGATION OF PFAS SITES
As with any remedial investigation effort, the keys to successful site investigations for PFAS compounds include accurate identification and characterization of the source or sources of contamination; definition of the contaminant migration pathways; and delineation of the extent of contaminant source areas and plumes.

When conducting site and remedial investigations on PFAS sites, specific precautions must be taken to avoid materials that could contain PFAS or PFAS precursors. Some of these materials are common to the environmental testing industry and/or field investigation sites, and if present, these materials could cause sample contamination and false positives, potentially resulting in unrepresentative data and a flawed conceptual site model. Similar confounding influences can occur at sites where the aerial deposition of dust or stack emissions containing PFAS might compromise sample integrity. While these site conditions are inherent to some projects, a rigid and prescriptive sampling plan will help prevent them from affecting sample quality. When combined with a robust QA/QC plan and approach to data validation, project teams have the ability to assess and quantify impacts on sample quality, providing reassurance that the data collected is indicative of the environmental media at the site and not affected by sample contamination.

While most PFAS investigations are currently initiated in response to the identification and presence of PFOA and PFOS in soil and groundwater, investigations and conceptual site models should also consider the potential presence of other PFAS compounds and the identification of precursor compounds that could affect the success of remediation approaches and regulatory compliance strategies. Depending on the site and the nature of the products released, innovative screening technologies — including but not limited to commercially available mobile laboratory equipment capable of performing USEPA Method 537 and ion screening probes, as well as field screening for indicator compounds such as alternate AFFF ingredients — may be used to help guide site investigations and provide efficiencies to the project team. These innovative techniques are still in development, and care must be taken to select appropriate screening techniques that provide the results needed for informed decision making. By combining innovative screening techniques with the collection of meaningful analytical data — which might include off-site analysis for USEPA Method 537, Total Oxidizable Precursors (TOP) Assay, and Particle Induced Gamma Emission (PIGE) Spectroscopy — the investigation can be completed efficiently while providing the data needed to develop an accurate and defensible conceptual site model to use as the basis for a comprehensive PFAS compliance strategy and, if necessary, the evaluation and design of remediation approaches.
Finally, no field investigation is complete without assessing the geologic, hydrogeologic and geochemical conditions that control contaminant fate and transport. Depending on the site, various degrees of investigation may be needed to determine the site stratigraphy and identify preferential migration pathways and physicochemical conditions that must be taken into account when assessing risk and remedial technologies. Care must be taken to define the site hydrostratigraphy at the resolution needed to understand the migration of contaminants while avoiding the expense of collecting unnecessary data. By employing these approaches at PFAS sites, scientists and engineers can efficiently develop an accurate and reliable conceptual site model to use as a basis for remedial design.

**REMEDIAION**

The chemical properties that make PFAS compounds ideal for fighting fires and repelling water also make them challenging to remediate using conventional techniques. While ex-situ technologies are viable, care must be taken to select treatment processes and design systems that are both effective and economically viable. Current ex-situ technologies rely on the removal of PFOS and PFOA from aqueous solution using various binding agents in combination with absorbent media and/or reverse osmosis membranes.

Once PFAS have concentrated within treatment media or concentrate streams, the resulting concentrate must be incinerated, landfilled or otherwise disposed of. While the environmental industry is focused on developing reliable remedial techniques for PFAS, new technologies have demonstrated varying degrees of success. When selecting a remedial approach, it is important that parties consider their specific remedial goals, the environmental setting and location of contaminant mass, and marry these factors with the most appropriate remedial technologies.

**THE BURNS & McDonnell DIFFERENCE**

Burns & McDonnell is uniquely qualified to navigate the uncertainties surrounding projects associated with PFAS. Our 118-year history is firmly grounded in assisting the industries affected by PFAS contamination. Simply put, we know the industries affected by PFAS and have extensive experience helping our clients address challenges resulting from emerging contaminants and new regulations. Our specialized understanding and knowledge of the processes and systems resulting in PFOA and PFOS contamination allow us to focus investigation efforts on areas with the highest probability of PFAS impact. This knowledge and approach saves time and money.

Burns & McDonnell is currently involved in several projects pertaining to PFAS contamination. We have been contracted to assess potential PFAS risks to a municipal water supply, characterize surface and subsurface PFAS impacts associated with an AFFF concentrate release, provide professional and engineering services surrounding the management of PFAS-containing landfill leachate, and have begun regulatory negotiations on corrective action at firefighting training grounds.

Our environmental experience is founded on Burns & McDonnell’s long history of designing environmental infrastructure and water treatment systems. We have extensive experience planning, coordinating, overseeing and interpreting field studies using the traditional and innovative techniques required to accurately identify and define PFAS impacts under a variety of site settings and subsurface conditions. Our team has developed groundwater flow models to assess the fate and transport of contaminants, estimated impacts to receptors, quantified environmental risks and liabilities, and evaluated potential remedial actions. Our industry-leading professionals present results within the context of client concerns and priorities to support well-informed and cost-effective decision making. We are well known in the regulatory community and have experience addressing past emerging contaminants such as dioxins and furans, 1,4-dioxane, and methyl tert-butyl ether.

When sites require active remediation, Burns & McDonnell can deliver comprehensive remediation services, including analysis of cleanup alternatives, remedial investigations, feasibility studies, remedial design services, construction of remedial systems using our EPC project delivery model, and remedial system operation and maintenance (O&M) and optimization.
Having performed environmental cleanups from the initial stages of identification of the problem through development of the remedy and closure for hundreds of sites, we understand that selecting the best remedial approach is critical to cost-effective cleanups and site closure. We are well versed in the in-situ and ex-situ treatment technologies historically employed and currently under development for PFAS remediation. Our combination of technical capabilities and regulatory knowledge allows us to carefully evaluate all options available for addressing these emerging contaminants. Our overall objective is to provide maximum value to our clients by effectively managing risk and minimizing cost.

REFERENCES

- USEPA, 2009. Provisional Health Advisories for Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS). January, 8.

BIOGRAPHIES

BRIAN HOYE, PG, is a senior geologist and project manager at Burns & McDonnell who has served on and managed a variety of environmental projects for private-sector and Department of Defense clientele. His practice has focused on issues surrounding emerging contaminants, new environmental regulations and emerging site investigation techniques, which he uses to develop informed and focused approaches to the environmental challenges facing his clients. Brian serves as a core member of the Burns & McDonnell remediation practice and leads the firm’s PFAS technical group.

JOHN HESEMANN, PE, is a geological and environmental remediation engineer with more than 18 years of professional experience in a variety of earth engineering fields. He has participated in more than 100 remediation projects in 17 states. John’s experience is focused on the selection, design, implementation and evaluation of environmental remediation technologies. He is the remediation practice leader for the Burns & McDonnell Environmental Group and supports nationwide remediation field implementation, optimization and O&M efforts. John specializes in rapid remedial progress through effective remedy selection, pilot testing, design, field application and optimization. He has served on the Interstate Technology and Regulatory Council (ITRC) Green and Sustainable Remediation Team and has written, presented and published several technical papers on in-situ remediation and other topics.