Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water: Guides for Local and State Leaders

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Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water: Guides for Local and State Leaders

GUIDES
Scientific Overview of PFAS and Drinking Water
Monitoring and Occurrence of PFAS in Drinking Water
Treatment and Mitigation of PFAS in Drinking Water
PFAS Risk Communications

These guides were developed to help local and state leaders understand the current scientific evidence as they evaluate the risk of PFAS contamination of drinking water. The guides can help people engage their community members, drinking water providers, local and state regulatory agencies, and federal agencies to address PFAS in drinking water.

A class of thousands of synthetic organic chemicals, not enough is known about the health impacts of most PFAS, but even small doses of several of the most-researched compounds can lead to health issues. Detected in drinking water and drinking water sources throughout the United States, the chemical properties of PFAS make them difficult to treat and remove using conventional water}

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Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water

Scientific Overview of PFAS and Drinking Water

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**Introduction to Per- and Polyfluoroalkyl Substances (PFAS)**

A class of thousands of synthetic organic chemicals, PFAS are found in a variety of industrial and consumer applications, from clothing and food wrappers to firefighting foam. Designed for long-term stability, temperature resistance, friction reduction, and oil and water repellency, PFAS, often referred to as “forever chemicals,” do not easily break down in the environment. Not enough is known about the health impacts of most PFAS, but even small doses of several of the most-researched compounds can lead to health issues. Anyone can be exposed to these toxic substances.\(^1\)

These guides were developed to help local and state leaders understand the current scientific evidence as they begin to address potential PFAS contamination. The information in these guides can help people engage community members, drinking water providers, local and state regulatory agencies, and federal agencies in addressing PFAS in drinking water. This first guide provides an overview of the current scientific evidence of PFAS occurrence and toxicology as well as what remains unknown and requires additional research. It explains the properties, history, toxicology, exposure routes, and the current status of federal and state regulations of PFAS.

Detected in drinking water and drinking water sources throughout the United States, the chemical properties of PFAS, such as the strength of the carbon-fluorine bonds, make them difficult to treat and remove using conventional water treatment processes.

In 2016, the U.S. Environmental Protection Agency (EPA) developed a lifetime health advisory level of 70 nanograms per liter (ng/L) or parts per trillion (ppt) for two PFAS: perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), individually or combined. This health advisory, however, is not an enforceable standard. In the absence of enforceable federal regulations, several U.S. states adopted or proposed drinking water standards for specific PFAS.

**PFAS Have Unique Chemical Properties**

PFAS include thousands of synthetic chemicals and are made up of carbon chains in which at least one carbon atom is “perfluorinated,” meaning that other than its carbon-atom neighbors, it is bonded only to fluorine atoms.

Three primary characteristics, as described in Figure 1, differentiate PFAS from other chemicals and add to their chemical stability.\(^2\) First, PFAS have **carbon chain backbones** that can vary in chain length (number of carbon atoms) and impact their chemical stability, toxicity and persistence in the environment. Their different chemical structures make for diverse chemical properties and unique chemical names such as PFOS and PFOA.
The carbon chain can be designated as “long-chain” or “short-chain” PFAS. Long-chain PFAS are the PFAS most commonly found in the environment and are sometimes referred to as “legacy” PFAS, as they have been in use for their stable, water-repellent properties since the 1940s. While some U.S. manufacturers phased some of these legacy PFAS out of certain products and processes in the early 2000s, their persistence means that they continue to be present in the environment. Long-chain PFAS include those that have a sulfonic acid functional group (made up of sulfur, oxygen and hydrogen atoms — $\text{SO}_3\text{H}$) and contain six or more carbons or those that have a carboxylic acid functional group (made up of carbon, oxygen and hydrogen atoms — $\text{COOH}$) and contain eight or more carbons. Long-chain PFAS include PFOA and PFOS, which are the most commonly recognized PFAS.

Short-chain PFAS that have been utilized as replacements for long-chain PFAS are also persistent, and some may bioaccumulate and induce adverse human health effects. These PFAS are mobile and are even more difficult to remove from water. Short-chain PFAS are those with a sulfonic acid functional group and five or fewer carbons or those with a carboxylic acid functional group and seven or fewer carbons. Short-chain PFAS are just as difficult to break down, are just as persistent in the environment and are widely used in industry.

Another unique aspect of PFAS is the strength of their carbon-fluorine bonds, which makes PFAS resistant to breakdown through conventional water treatment processes. Due to their high thermal and chemical stability, PFAS are often referred to as forever chemicals. Last, functional groups also can increase or decrease the likelihood a particular PFAS will persist and accumulate.

Thousands of PFAS Have Been Produced

The EPA estimates that thousands of PFAS have been developed and used in industrial and consumer applications since the 1940s, but only about 600 PFAS are currently approved for commercial use in the U.S. PFAS are used in applications such as firefighting foam, furniture chemical coatings, food product containers (e.g., pizza boxes, wrappers) and water-repellent materials used in clothing (e.g., raincoats). Despite
numerous industry uses, detecting each PFAS in the environment may not be possible due to analytical limitations, as the most commonly used EPA-approved laboratory method (537.1) can measure only 24 PFAS of the thousands of PFAS that may be on the global market, according to a recent inventory.³

**National Attention Given to PFOA and PFOS**

The National Health and Nutrition Examination Survey (NHANES), conducted by the Centers for Disease Control and Prevention (CDC), detected four PFAS (PFOA, PFOS, PFHxS and PFNA) in more than 98% of 2,000 blood samples collected in 2003 and 2004.⁷ Due to their decades of widespread use, PFOA and PFOS are the PFAS most prevalent in the environment and in humans, so the health effects of these two PFAS are the most widely studied. They have been linked to adverse health effects, such as developmental issues in fetuses, testicular cancer, kidney cancer, liver effects, immune system effects, preeclampsia and elevated blood pressure during pregnancy, thyroid impacts, ulcerative colitis and high cholesterol.

Historically, the primary applications of PFOA included protective coatings and the production of nonstick surfaces, and those of PFOS included firefighting foam and water-repellent or stain-resistant products.⁸,⁹ Because of research that revealed harmful health effects, PFOS and PFHxS were phased out of production in the United States from 2000 to 2002, and eight major companies agreed to phase out the production and use of PFOA and some PFOA-related chemicals including PFNA in 2006 as part of the EPA’s PFOA Stewardship Program.¹⁰ However, PFOA, PFOS and other legacy PFAS may still be manufactured in other countries and may be present in materials imported into the U.S.¹¹ Alternative PFAS developed as replacements, including several short-chain PFAS, are still in production today and may pose problems.¹² The NHANES survey continues to detect PFAS (PFOA, PFOS, PFHxS and PFNA) in more than 95% of U.S. residents tested in 2018, the most currently available data.¹³

**PFAS Toxicology: PFAS Can Have Health Implications**

Research has shown that some PFAS, such as PFOA and PFOS, can have **adverse health effects at trace levels (ng/L or ppt)** on laboratory animals; limited research has been completed for human health impacts. While research into the potential health implications of these PFAS indicates reason for concern, there are still toxicological unknowns. Very little is known about a majority of PFAS, including their half-life, toxicity and bioaccumulation data. The Interstate Technical and Regulatory Council (ITRC) frequently updates its toxicological database as new health-related data become available.¹⁴ Table 1 presents current knowns and unknowns related to PFAS impacts on human health.¹⁴⁻¹⁸
Table 1 — Known and Unknown PFAS Human Health Implications

<table>
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<th>KNOWNS</th>
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| • Most people in the U.S. have been exposed to PFAS, and as of 2004, 98% of Americans had PFAS in their blood.\(^7\)  
• Exposure to certain PFAS may lead to liver damage, thyroid issues, testicular and kidney cancer, immune deficiencies, developmental effects, reproductive issues and cardiovascular effects.  
• Long-chain PFAS have longer half-lives in humans (>1 year) than short-chain PFAS (days to months), meaning long-chain PFAS take longer to exit the body after exposure. | • There is minimal information about a majority of individual PFAS, including half-life, toxicity and bioaccumulation data.  
• Short-chain versus long-chain PFAS’ toxicity is still under investigation and largely uncertain.\(^5\)  
• Carcinogenicity studies are available for only four PFAS (PFOS, PFOA, PFHxA and GenX).  
• Comprehensive epidemiological studies of communities with a known PFAS source, with the exception of PFOA, are generally lacking. Some studies, such as the C8 Science Panel and Faroe Islands Study, have investigated community effects.\(^17,19\)  
• Toxicological data for PFAS mixtures are limited but currently under investigation and noted by scientists as an important data gap for future research.\(^20,21\)  
• Biomonitoring data are somewhat limited for a majority of PFAS. |

PFAS in the Environment

PFAS are used in consumer products, industrial applications and firefighting foam. PFAS have been found in everyday items such as nonstick cookware, stain-resistant upholstered furniture, waterproof clothing, pizza boxes, dental floss, fast-food wrappers, microwave popcorn bags, waxes and paints. Industrial applications of PFAS include uses such as chrome plating, electronics manufacturing, and oil and mining operations. PFAS-based firefighting foams, known as Class B aqueous film-forming foam (AFFF), are designed to extinguish high-risk fires involving flammable liquids (e.g., gasoline, alcohol). The Department of Defense (DoD) and the Federal Aviation Administration (FAA) currently require use of AFFF at military airfields and many civilian airfields, but this is being phased out in the next several years (by 2023) following congressional action.\(^22\) The DoD is currently researching effective alternative foams.

PFAS Can Enter the Environment From Several Sources

There are multiple ways for PFAS to enter the environment, which can be classified as primary and secondary sources. Primary sources produce PFAS contamination, whereas secondary sources convey contamination produced by primary sources. Figure 2 presents examples of primary and secondary sources of PFAS that contribute to accumulation in the environment, specifically drinking water. Due to their strong carbon-fluorine bonds, PFAS do not significantly biodegrade, which makes them persistent in the environment and enables them to impact groundwater, surface water and ecosystems.
**AFFF** is used to extinguish flammable liquid fires. The largest stocks of AFFF are stored at commercial and private airports, military sites, chemical plants, and aboveground petroleum storage tank facilities. Many fire departments still use AFFF for training and emergency response. When AFFF is used, runoff may enter sewer or stormwater systems.

**Industrial facilities and incineration facilities** can release PFAS into the environment through liquid discharge, solid waste, disposal of contaminants in soil and/or **air emissions**. Industrial facilities in the U.S. have largely phased out PFOS, PFHxS, PFOA, and PFNA but continue to use short-chain PFAS in some applications. Incineration is one of the main methods used to destroy PFAS. Incineration facilities may discharge PFAS into the air during the incineration of materials. These materials include media and resin used during the treatment of PFAS in drinking water facilities. PFAS-containing air emissions may deposit PFAS back into the environment through settling and precipitation. Research is ongoing to characterize PFAS behavior in air emissions and to determine the conditions required for the destruction of PFAS during high-temperature incineration. Additional research is needed to establish standard methods for PFAS testing in air and to enhance our understanding of PFAS emissions and control options.

**Wastewater treatment plant effluent and biosolids** can contain PFAS. Because PFAS are used in many consumer products, they can be present in the wastewater conveyed by sewer systems to municipal wastewater treatment plants (WWTPs). Additional PFAS sources in WWTPs include AFFF runoff and PFAS-contaminated industrial waste. WWTPs are not equipped to remove significant levels of PFAS, which then may be present in treated wastewater that is discharged into surface waters or in the sewage sludge produced during the wastewater treatment process. This sludge is either disposed of or further treated to form biosolids, which can be applied to agricultural land as fertilizer.

**Landfills** receive a wide range of products containing PFAS, such as nonstick cookware, fast-food wrappers, furniture and water-resistant clothing. As rainwater filters down through landfills, it accumulates PFAS and other chemicals from decomposing products. This water, along with liquid from products’ natural
decomposition, is known as **landfill leachate**. Leachate containing PFAS can enter the environment through leaks in landfill liners. Additionally, landfill leachate is sometimes conveyed to WWTPs that ultimately discharge treated wastewater to surface waters. Like WWTPs, landfills do not produce PFAS but may serve as conduits for PFAS into water sources.

The inability of PFAS to biodegrade makes them highly persistent in the environment, and some of the more-mobile PFAS can travel through air and water to impact both groundwater and surface waters. **Figure 3** shows examples of how PFAS can travel through the environment from sources to water bodies.

**Figure 3 — PFAS Mobility in the Water Cycle**

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**PFAS Exposure Pathways**

Concern over PFAS contamination of **drinking water** supplies has grown over the past decade as health studies have linked exposure to particular PFAS with harmful health effects. To estimate public health exposure and risk, the EPA uses an assumption that 20% of PFOS and PFOA human exposure comes from drinking water, while the remaining 80% comes from alternative pathways. People can be exposed to PFAS through the following exposure pathways:
• **Drinking water** – Private wells, municipal water supplies, bottled water.
• **Consumer products** – Food packaging, stain- and water-resistant clothing, carpets, and furniture.
• **Food consumption** – Food enclosed with packaging containing PFAS; in food grown where biosolids are applied or from animals exposed to PFAS.
• **Air emissions** – Areas where air emissions or dust containing PFAS are present.
• **Occupational exposure** – People working manufacturing jobs where PFAS are used or produced, firefighters, landfill operators and PFAS-containing biosolids applicators.

**PFAS in Drinking Water Are Largely Unregulated in the United States**

There is currently no enforceable federal standard for PFAS in drinking water. In early 2021, the EPA developed a regulatory determination for PFOS and PFOA in drinking water and is continuing with implementing the national primary drinking water regulation development process for PFOS and PFOA. Several states have set maximum contaminant levels (MCLs) in drinking water for as many as six PFAS compounds, and others are in the process of doing so. The regulatory process discussed below applies to the drinking water sector.

**EPA Required Public Water Systems to Gather Data on PFAS**

Published by the EPA every five years, the Unregulated Contaminant Monitoring Rule (UCMR) requires certain public drinking water systems, primarily those that serve more than 10,000 individuals, to sample the water they distribute for up to 30 contaminants that are not federally regulated. UCMR contaminants are generally considered emerging contaminants, such as PFAS. Key provisions of the UCMR, including contaminants sampled and results, can be found on the EPA’s website.

UCMR 3 was conducted from 2013 to 2015 and included sampling for six PFAS — PFOS, PFOA, PFBS, PFHxS, PFHpA and PFNA. PFOS and PFOA were detected in 1.9% and 2.4% of public water systems, respectively. However, select water systems were tested, and only these six PFAS were measured. Reporting limits during testing were relatively high (10 to 90 ng/L) compared with current analytical capabilities; therefore, PFAS reported as “not detected” could still be present but at levels below the historical reporting limits. UCMR 4, conducted from 2018 to 2020, did not include any PFAS.

UCMR 5, to be conducted from 2022 to 2026, will include 29 PFAS. UCMR 5 will also include additional water systems that were not included in UCMR 3. It is expected to provide information related to additional PFAS occurrence and exposure.

**The EPA Developed Lifetime Health Advisory Levels for PFOS and PFOA**

Following UCMR 3, the EPA established nonenforceable lifetime health advisory levels for PFOS and PFOA in 2016. The lifetime health advisory level for PFOS and PFOA is 70 ng/L (or 70 ppt) individually or combined, based on the estimated exposure for the most at-risk population — pregnant and nursing women. The lifetime health advisory assumes a drinking water consumption of 0.054 liters per kilogram of body weight per day and that drinking-water consumption makes up 20% of a human’s PFOS and PFOA exposure.
Additional details regarding these assumptions are provided in the EPA’s Drinking Water Health Advisories for PFOA and PFOS webpage.\textsuperscript{29}

**The EPA Is Taking Steps Toward Establishing a Drinking Water Standard for PFAS**

The EPA developed the *PFAS Action Plan* in 2019 to advance its support for cleanup efforts, toxicology, monitoring in drinking water, emerging research, cleanup enforcement and risk communication.\textsuperscript{30} One of the major provisions of the action plan was to decide, by the end of 2019, whether to regulate PFOS and PFOA under the SDWA.\textsuperscript{31} In February 2021, the EPA made a final determination to regulate PFOS and PFOA. If the EPA proceeds with the regulatory process laid out in the SDWA, it will have up to 3.5 years to establish MCLs. As part of the *PFAS Action Plan*, the EPA also will consider whether there is a need to regulate PFAS beyond PFOS and PFOA.

**Regulating PFAS by Chemical Characteristics**

Some experts and environmental advocates suggest regulating PFAS as a class rather than each chemical individually (i.e., establishing a single drinking water standard for the entire PFAS family). Other potential regulatory strategies include regulating groups of PFAS, also referred to as subclasses, that have similar chemical properties (e.g., perfluorinated carbon chain length, functional groups, degradation products), common adverse health effects, co-occurrence with other PFAS or a combination of these characteristics.

**States Are Developing PFAS Guidelines**

In the absence of enforceable federal regulations, several states have set MCLs for drinking water, and other states are in the process of doing so.\textsuperscript{32} Federal and state PFAS health advisory levels, MCLs (established and proposed), guidance levels and action levels differ due to the various toxicological endpoints and assumptions used as the basis of drinking water guidelines. The EPA and states use human health risk assessment (federal-and state-conducted evaluations) to determine PFAS toxicity. For example, the EPA used a developmental endpoint for PFOA and PFOS exposure, whereas some states use a liver or an immune-related endpoint.\textsuperscript{33} Additionally, some states have set levels for additional PFAS (besides PFOA and PFOS) that were determined to have adverse health effects or to be more heavily present in drinking water supplies. For a complete list of state and federal PFAS guidance, please visit the ITRC and American Water Works Association (AWWA) PFAS regulation summaries.\textsuperscript{34,35}

**Overview of Current PFAS Research**

Extensive research is being conducted by scientists in universities, government agencies and the private sector to better understand PFAS occurrence, transport, detection, toxicity, exposure and treatability. These agencies include DoD, the National Institute of Environmental Health Sciences (NIEHS) through the National Institutes of Health (NIH), the EPA and others.\textsuperscript{26,36,37} To fulfill the goals laid out in its *PFAS Action Plan*, the EPA is continuing to conduct research related to PFAS detection in water, wastewater, landfill leachate, air emissions, soil and other matrices.
In September 2019, the CDC and the Agency for Toxic Substances and Disease Registry (ATSDR) announced the start of a study to investigate the health effects from PFAS-contaminated drinking water, which is the first study to look at health effects from PFAS at multiple sites across the U.S. Additionally, several other programs are underway. For example, the Sources, Transport, Exposure and Effects of PFASs (STEEP) Superfund Research Program, headed by the University of Rhode Island, is directly addressing the human exposure pathways by fingerprinting drinking water and fish.

**Key Takeaways**

After decades of use in everything from clothing to firefighting foam, PFAS are ubiquitous in the environment. As concern over PFAS contamination of drinking water grows, not enough is known about the adverse health impacts of most PFAS. Research continues to reveal more about PFAS' toxicity and fate in the environment:

- PFAS enter the environment from numerous sources and have been detected in drinking water sources throughout the U.S.
- PFAS are difficult to remove from drinking water sources because of their unique chemical properties, particularly their persistence in the environment, mobility in water systems and potential for bioaccumulation.
- PFAS have been detected in treated drinking water at ng/L (ppt) levels.
- PFOA and PFOS have been linked to adverse health impacts at these low levels, and research related to health impacts of an increased number of PFAS is ongoing.
- Federal regulations for PFAS in drinking water do not currently exist, but in early 2021 the EPA began implementing the national primary drinking water regulation development process (e.g., MCLs) for PFOS and PFOA levels in public drinking water.
- Some states have set advisory guidelines or MCLs for various PFAS or groups of PFAS in public drinking water.
- Research related to PFAS contamination is ongoing and has significantly advanced our understanding of PFAS' health impacts and best practices for the prevention of future PFAS contamination, mitigation of existing contamination and treatment of PFAS in drinking water. However, many unknowns remain, and extensive research is underway to address these unknowns.

**References**

Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water

Monitoring and Occurrence of PFAS in Drinking Water
PFAS Contamination of Drinking Water

Several of the most-researched per- and polyfluoroalkyl substances (PFAS) have been linked to human health issues at small doses and detected in drinking water and drinking water sources throughout the United States. A class of thousands of synthetic organic chemicals, PFAS are found in a variety of industrial and consumer applications, from clothing and food wrappers to firefighting foam, and after decades of use, PFAS contamination is widespread. The chemical properties of PFAS, particularly the strength of the carbon-fluorine bonds, make them difficult to treat and remove using conventional water treatment processes.

This guide describes how communities can evaluate the risk of PFAS contamination by leveraging existing data and conducting sampling of water and other environmental matrices (e.g., soil) to identify potential PFAS sources that may need remediation. For more information on the basics of PFAS chemical properties, toxicity and more, please see the AAAS EPI Center’s PFAS and Drinking Water: A Scientific Overview.

Evaluating PFAS occurrence in drinking water requires a robust monitoring plan. A PFAS monitoring plan should consider sampling locations, frequencies, cost and other water quality parameters. Potential sampling locations include drinking water distribution systems, drinking-water treatment plants (referred to as WTPs) and WTP source waters. PFAS monitoring can occur over a period of months or years, depending on location, number of contamination sources and watershed characteristics. PFAS analysis can be costly, since limited analytical techniques are available to measure PFAS levels in water and because the cost for analysis can range from $200 to $350 per water sample. Monitoring additional water quality parameters is also important, since these can help identify contamination sources and influence the efficacy of different treatment approaches.

PFAS Contamination Calls for a ‘One Water’ Approach

While the focus of this guide is to examine the impacts of PFAS on drinking water, the persistent nature of PFAS make them ubiquitous in the water cycle. For that reason, addressing PFAS contamination requires a holistic approach that considers more than just drinking water alone. The One Water concept is a holistic approach to more effectively manage drinking water, wastewater, stormwater, surface water and groundwater together. PFAS epitomize One Water contaminants; they are present in all parts of the water cycle and will concentrate over time. Evaluating PFAS from a One Water perspective allows scientists and engineers to understand PFAS migration from a source into the environment and to determine the best management point.

WTPs typically utilize groundwater or surface water as raw water sources for treatment. After the drinking water is used by the community, it is conveyed to municipal wastewater treatment plants (WWTPs) through sewer systems. Once treated through the WWTP, the water is discharged into surface waters, which may serve as drinking water supplies for downstream communities after some time in the environment. The One Water concept is illustrated as a simplified schematic shown in Figure 1.
While WTPs and WWTPs are designed to remove traditional contaminants, many are not equipped to reduce PFAS levels. PFAS continue to be cycled between various waters when they are not removed or destroyed.

**Figure 4 — Simplified One Water Cycle**

**Existing Data Can Help Determine a Community’s Risk of PFAS Contamination**

Existing PFAS occurrence data can help communities evaluate the risk of PFAS contamination in their water resources. Data sources include monitoring mandated or carried out by the U.S. Environmental Protection Agency (EPA), state agencies, utilities and/or university researchers. In addition to the occurrence data, communities need information on potential sources of PFAS, including industrial production and use, airfields, and firefighting and firefighter training use.

The EPA’s Third Unregulated Contaminant Monitoring Rule (UCMR 3) provides sampling data from nationwide monitoring of treated drinking water (i.e., finished water) from public drinking water systems, primarily those that serve more than 10,000 individuals. Between 2013 and 2015, 36,000 samples obtained from the treated water of 4,920 public water systems (out of more than 148,000 public water systems in the United States) were analyzed for a set of contaminants suspected to be present in drinking water but for which the EPA had not set health-based standards. UCMR 3 included six well-known PFAS for monitoring, although many more PFAS may exist in the environment. Moreover, UCMR 3 reporting limits for these PFAS were relatively high (10 to 90 ng/L) compared with current analytical capabilities; therefore, PFAS that were reported as “not detected” still could have been present but at levels below detection limits at the time.
Finally, UCMR 3 sampling focused primarily on large public water systems serving more than 10,000 individuals, and these results represent only a fraction of public water systems and do not include information about private wells and other small water systems.

Two PFAS, PFOS and PFOA, were detected above reporting limits of 40 ng/L and 20 ng/L in 1.9% and 2.4% of these systems, respectively. Since the completion of UCMR 3, additional PFAS and lower levels of the six UCMR 3 PFAS have been detected in waters throughout the United States, largely due to improved analytical capabilities. However, UCMR 4, conducted from 2018 to 2020, did not include any PFAS. UCMR 5, to be conducted from 2022 to 2026, will include additional PFAS. The current plan is for 29 of the 30 contaminants in UCMR 5 to be PFAS. UCMR 5 will also include many more water systems than were included in UCMR 3. UCMR 5 also is expected to provide information related to additional PFAS occurrence and exposure.

Beyond federal sampling, some states have initiated PFAS characterization programs that try to identify sources of PFAS in drinking water. These initiatives have focused on PFAS measurements at or near potential primary sources, such as those that directly contribute PFAS to the environment (e.g., industrial discharge, firefighting foam containing PFAS) and secondary sources or those that indirectly contribute PFAS to the environment through conveyance of PFAS from primary sources (e.g., WWTP effluent, landfill leachate).

Few states have conducted extensive sampling campaigns, and the sampling locations do not necessarily include all sources posing potential PFAS contamination risks to water resources. Table 1 presents examples of state PFAS sampling campaigns and provides the year the initiatives began, the type of water sampled and the primary goals of sampling. In some cases, states sampled directly from industrial facility outfalls and/or landfill leachate.

Table is not exhaustive, and additional state sampling initiatives can be found on the EPA’s website.

Table 1 — Examples of State PFAS Sampling Campaigns

<table>
<thead>
<tr>
<th>STATE</th>
<th>YEAR INITIATED</th>
<th>WATERS SAMPLED</th>
<th>KEY CONSIDERATIONS AND PRIMARY GOALS OF CAMPAIGNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEW JERSEY</td>
<td>2007</td>
<td>Groundwater, surface water, finished water</td>
<td>Multiple past and ongoing studies to determine PFAS occurrence in the environment, drinking water sources, watersheds, aquatic life, surface water and sediment.</td>
</tr>
<tr>
<td>MASSACHUSETTS</td>
<td>2016</td>
<td>Groundwater, surface water, finished water</td>
<td>Four-year sampling study of probable sources of contamination (airports, industrial facilities) and public water system drinking water.</td>
</tr>
<tr>
<td>STATE</td>
<td>YEAR INITIATED</td>
<td>WATERS SAMPLED</td>
<td>KEY CONSIDERATIONS AND PRIMARY GOALS OF CAMPAIGNS</td>
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<td>---------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>NEW HAMPSHIRE⁹</td>
<td>2016</td>
<td>Groundwater, surface water, finished water</td>
<td>Evaluate the extent of PFAS contamination in drinking water and identify contamination sources.</td>
</tr>
<tr>
<td>MICHIGAN⁶</td>
<td>2017</td>
<td>Surface water, finished water, wastewater</td>
<td>Evaluate PFAS occurrence in waters with confirmed or probable sources of contamination — military sites, industrial facilities, landfills, aqueous film-forming foam (AFFF) discharge locations.</td>
</tr>
<tr>
<td>NORTH CAROLINA⁶</td>
<td>2017</td>
<td>Groundwater, surface water, finished water</td>
<td>Evaluate the extent of PFAS contamination in rivers and groundwater by a manufacturing facility that utilizes and produces PFAS, and assess PFAS occurrence in statewide drinking water sources.</td>
</tr>
<tr>
<td>PENNSYLVANIA⁸</td>
<td>2018</td>
<td>Groundwater, surface water</td>
<td>Taking a phased approach to determine the extent of PFAS contamination in drinking water sources located near potential primary sources (manufacturing, military sites, firefighting training sites) and secondary sources (landfills).</td>
</tr>
<tr>
<td>CALIFORNIA⁷</td>
<td>2019</td>
<td>Groundwater, surface water, finished water</td>
<td>Evaluate PFAS contamination from primary sources (manufacturing, airports) and secondary sources (landfills) as well as groundwater wells. The campaign is projected to be completed in 2020. A second phase of testing will be initiated after completion of the initial study. More assessment will be required in coming years.</td>
</tr>
</tbody>
</table>

Check with local universities, researchers and water utilities that may have performed sampling and PFAS analysis of water resources. Universities or researchers may also have evaluated options advancing analytical method development, remediation or treatment of a community’s water supply. Relatively few drinking water utilities conduct PFAS sampling unless required to by law, and utility-led initiatives are usually limited.

**Communities at Risk of PFAS Contamination Should Develop a Robust Monitoring Plan**

Critical aspects of developing an effective PFAS monitoring plan include identifying and coordinating multiple agencies and stakeholders (e.g., affected residents) that need to be involved as well as identifying appropriate sampling locations, analytical methods and sampling frequency. A communication plan to
inform and engage the community is also essential and should include plans for how to respond to the PFAS detection above or below the federal- and state-specific criteria.

### Identifying Sampling Locations to Determine Sources of Contamination

Analytical costs, complex water matrices, and trace PFAS concentrations and cross-contamination can make sampling efforts costly and challenging. To allocate time and resources appropriately, develop a **robust PFAS sampling plan.** Figure 2 presents an example of PFAS travel routes from sources of contamination to the community and recommended sampling components.

One component of a sampling plan is to provide a **community impact assessment** to sample treated drinking water at the WTP or within the distribution system to identify which communities are impacted. If PFAS are found, more sampling should take place over weeks or months after the contamination is identified in order to determine the risk to public health.

A second component of a PFAS sampling plan is to conduct **WTP sampling** at the WTP surface water intake(s) and/or groundwater well(s). The length of time an intake should be sampled depends on the location, as some sites are more impacted than others by seasonal changes. For surface water plants, the intake(s) should be sampled multiple times over an extended period (e.g., six to nine months) to account for seasonality or other variations in water quality typically associated with surface water sources.

For groundwater sampling, a few samples over a short period (e.g., weeks or months) may be adequate to determine typical PFAS concentrations. If PFAS are not detected in raw (untreated) water samples after several sampling events, sampling frequency may be reduced (e.g., to yearly) to check for PFAS contamination. The surface water intake and/or groundwater well sampling frequencies in the monitoring plan should be determined based on how variable the water sources are. Frequency can range from weekly to monthly, depending on results of initial data collection.

A third component of a PFAS sampling plan is **discharger tracking and source water identification.** The purpose of this component is to better understand the sources of PFAS contamination in drinking water. Discharger tracking and source water identification include sampling locations throughout the WTP source water, such as tributaries that discharge into a river or lake or additional groundwater well locations. Discharger tracking and source water identification should also include an evaluation of potential sources of contamination such as airports, firefighting training facilities, manufacturing facilities, landfills and WWTPs. WTP source water contamination by PFAS is usually localized, meaning contaminants are likely to occur where a primary source discharges into or infiltrates WTP source water. However, it is not always clear where those sources of contamination are located.

Additional sampling components may be conducted as necessary to evaluate less-obvious contamination sources, including secondary sources such as waste management units (e.g., landfills) that receive PFAS wastes. Sampling efforts should continue to monitor all possible PFAS contamination sources that can be identified. It is difficult to identify all contamination sources, but detailed sampling at multiple points upstream and downstream of potential sources can help identify the contamination sites by comparing
PFAS levels at these sites with raw (untreated) water entering the WTP. Consulting with PFAS experts in the water industry or other utilities experienced in PFAS contamination issues is advised.

**Figure 5 — Example of a PFAS Sampling Approach**

**Analytical Methods for PFAS Measurement Are Available**

Measuring PFAS levels in water presents several analytical challenges, including different degrees of accuracy. Analytical methods vary with respect to the number and type of PFAS that can be measured, detection limits (i.e., the lowest levels of PFAS that can be reliably measured), applicable sample matrices (i.e., materials such as water or soil) and cost. EPA-validated methods are available for measuring PFAS levels in drinking water, surface water, groundwater and wastewater.

While reliable methods are also available (or in development) for other materials possibly contaminated with PFAS (including wastewater, landfill leachate, biosolids, soil and materials such as concrete), these methods are not yet EPA-validated. Accurately measuring PFAS concentrations at the ng/L (ppt) level requires
expensive laboratory equipment and careful sample preparation. More extensive preparation procedures and more-complicated laboratory methods are necessary for samples of solid materials (e.g., soil). At present, most analytical methods target a set of fewer than 40 individual PFAS chemicals, whereas thousands of PFAS exist and at least 600 are used in industrial and consumer product applications.\(^\text{12}\)

Table 2 presents EPA-validated laboratory methods that can be used to measure PFAS levels, along with the number of compounds that can be analyzed, applicable sample matrices and detection limits. Detection limits vary among different individual PFAS and laboratories. EPA Method 537 was published in 2009 as the first procedure for measuring PFAS in drinking water, and this method was used during UCMR 3. The EPA has since published additional methods to measure additional compounds. With EPA Methods 537.1 and 533, a total of 29 short- and long-chain PFAS can be measured.\(^\text{13}\)

### Table 2 — EPA-Validated PFAS Laboratory Methods

<table>
<thead>
<tr>
<th>METHOD</th>
<th>APPLICABLE SAMPLE MATRICES</th>
<th>NUMBER OF PFAS ANALYZED</th>
<th>BENEFITS/CHALLENGES</th>
<th>LOWEST CONCENTRATION MINIMUM REPORTING LEVEL (LCMRL)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA METHOD 537(^\text{16})</td>
<td>Drinking water</td>
<td>14</td>
<td>Higher detection limits than newer drinking water methods, effective capture of long-chain PFAS, partial capture of short-chain PFAS</td>
<td>2.9 to 14 ng/L</td>
</tr>
<tr>
<td>EPA METHOD 537.1(^\text{14})</td>
<td>Drinking water</td>
<td>18</td>
<td>Lower detection limits than EPA Method 537, ability to measure four additional PFAS</td>
<td>0.53 to 6.3 ng/L</td>
</tr>
<tr>
<td>EPA METHOD 533(^\text{17})</td>
<td>Drinking water</td>
<td>25</td>
<td>Effective capture of short-chain PFAS</td>
<td>1.4 to 16 ng/L</td>
</tr>
<tr>
<td>EPA METHOD 8327(^\text{18})</td>
<td>Surface water, groundwater, wastewater</td>
<td>24</td>
<td>Ability to measure PFAS in more complex aqueous matrices, high detection limits that make the method more useful as a screening method</td>
<td>In development</td>
</tr>
</tbody>
</table>

*Considers both accuracy and precision of analytical method — based on the lowest true concentration for which future recovery is predicted, with high confidence (99%), to fall between 50% and 150%
Useful Tips for PFAS Sampling
When sampling water for PFAS analysis, care must be taken to prevent contamination, as many materials can skew results. Specific procedures must be followed, which include avoiding the use and wearing of everyday materials that contain PFAS, such as insect repellent; sunscreen; Tyvek boot covers; water- or stain-resistant clothing, including some rain jackets; permanent felt markers; plastic clipboards; cosmetics; and waterproof notebooks. Avoid the use of all PFAS-containing materials that may potentially contaminate water samples during sampling events. It is also important to include quality assurance or control to verify the presence of PFAS cross-contamination. Additionally, it is important to check with the laboratory performing analytical services prior to sampling to determine whether specific sample collection procedures are recommended, as many laboratories require the use of laboratory-supplied containers.

Several parameters should be measured and recorded when performing PFAS sampling, including environmental conditions (e.g., stream flow, water depth, distance from shoreline, water matrix, etc.), water quality parameters (e.g., pH, turbidity, organics), groundwater well conditions (e.g., well depth, time purged, water table characteristics, well construction) and location (e.g., GPS coordinates, groundwater well name). Some of this information, such as groundwater well depth and water table characteristics, may provide insight as to where PFAS contamination originates. Other information, including surface water stream flow, can account for PFAS concentration variations between multiple sampling events.

Key Takeaways
PFAS contamination in U.S. drinking water sources is widespread due to PFAS use in commercial products (e.g., nonstick cookware, water-resistant fabrics) and industrial applications (e.g., chrome plating, oil recovery) and subsequent disposal of consumer products and industrial waste discharge. It can be difficult to identify all sources of contamination; detailed sampling at multiple points upstream and downstream of potential sources is often required. Evaluating PFAS occurrence in drinking water requires a robust monitoring plan.

Key takeaways from this PFAS monitoring and occurrence guide include:

- After entering the environment, PFAS are continuously cycled between surface water, groundwater, drinking WTPs and WWTPs due to the inability of WTP and WWTP technologies to remove these chemicals.
- Our knowledge related to PFAS transport in the environment is continuously expanding as more research is conducted.
- Due to the persistent nature of PFAS, taking a holistic, One Water approach is ideal to identify potential sources of PFAS in impacted drinking water communities.
- Communities can examine previously conducted PFAS studies, such as the EPA’s UCMR 3 program or state-led PFAS sampling programs, as a first step in determining the potential for PFAS
contamination. Local universities, researchers and water utilities may have performed sampling and PFAS analysis of water resources.

- If contamination is suspected or identified, communities should develop a PFAS monitoring plan. Any monitoring plan should consider sampling locations, frequencies, cost and other water quality parameters.
- Measuring PFAS levels in water presents several analytical challenges. Analytical costs, complex water matrices, trace PFAS concentrations and cross-contamination can make sampling efforts costly and challenging.
- Sampling protocols and analytical methods are available for water utilities to measure the levels of PFAS in their finished water and to determine whether additional treatment is necessary to remove PFAS.

References

Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water

Treatment and Mitigation of PFAS in Drinking Water
PFAS and Drinking Water

A number of the most-researched per- and polyfluoroalkyl substances (PFAS) have been linked to human health issues at small doses and detected in drinking water and drinking water sources throughout the United States. A class of thousands of synthetic organic chemicals, PFAS have been used in a variety of industrial and consumer applications, from clothing and food wrappers to firefighting foam, and after decades of use, PFAS contamination is widespread.\(^1\) The chemical properties of PFAS, particularly the strength of the carbon-fluorine bonds, make them difficult to treat and remove using conventional water treatment processes.

This guide introduces established drinking water technologies that can remove PFAS from drinking water as well as emerging and innovative PFAS treatment technologies still in development. For more information on the basics of PFAS’ chemical properties, toxicity, monitoring and more, please see the AAAS EPI Center’s guides *PFAS and Drinking Water: A Scientific Overview* and *PFAS Monitoring and Occurrence in Drinking Water*. In 2016, the U.S. Environmental Protection Agency (EPA) developed a lifetime health advisory level of 70 ng/L or parts per trillion (ppt) for two PFAS — perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), individually or combined — but this health advisory is not an enforceable standard.

In the absence of enforceable federal regulations, many U.S. states adopted or proposed drinking water standards for specific PFAS. PFAS cannot be easily removed by most municipalities’ existing conventional water treatment technologies. Effective PFAS treatment technologies can be costly and vary in their effectiveness at removing different PFAS. Therefore, water utilities typically approach PFAS treatment by conducting preliminary small-scale studies to assess treatability and to determine the best treatment for the individual water system. Results can vary significantly based on site-specific factors such as water quality, site availability and waste treatment options.

Removing PFAS From Drinking Water

Existing advanced treatment technologies are able to remove PFAS from water, but they vary in PFAS treatment effectiveness and can be costly. PFAS removal effectiveness can depend on the PFAS properties (e.g., chain length, functional groups) and other water quality constituents that may interfere with treatability.\(^2\) Long-chain PFAS are the PFAS most commonly found in the environment and are sometimes referred to as “legacy” PFAS, as they have been in use for their stable, water-repellent properties since the 1940s, and most were phased out in the United States in the early 2000s.\(^3\) Alternatively, short-chain PFAS have been used as replacements for long-chain PFAS; they can be highly mobile in water and soil and are difficult to break down.\(^1\)

Advanced treatment methods for PFAS removal also come with operational challenges, including changes in day-to-day operations, expensive costs for construction and operation, and the production of PFAS-contaminated waste that requires proper management and disposal. In addition to treatment at water facilities, PFAS contamination can be controlled through several other measures, such as environmental
cleanup (i.e., site remediation) upstream of the drinking water treatment plant (WTP), shutdown or mixing of contaminated drinking water sources, and in-home treatment.

PFAS treatment produces waste that requires proper disposal to prevent it from cycling back into the water system. When sent to a landfill, PFAS-contaminated waste may leach into soil or water. Incineration is one of the main methods used to destroy PFAS. Incineration facilities discharge air emissions when incinerating materials such as media and resin used during the treatment of PFAS in drinking water facilities. Without incineration temperatures above 1,400 degrees Celsius and contact times long enough to destroy the PFAS, these incineration facilities have the potential to discharge PFAS-containing air emissions that deposit PFAS back into the environment through settling and precipitation. Research is ongoing to characterize PFAS’ behavior in air emissions and to determine the conditions required for the destruction of PFAS during high-temperature incineration.

**Effective PFAS Treatment Methods**

Several established water treatment technologies provide varying degrees of PFAS removal. The three most commonly used are **activated carbon, ion exchange (IX)** and certain **semipermeable membranes**. Each of these processes has benefits and limitations, including extent of treatability, secondary water quality benefits, ease of implementation, waste disposal challenges and capital and operating costs. Additional information on these technologies can be found in the EPA Drinking Water Treatability Database.

**Activated Carbon Treatment Methods Reduce PFAS**

Adsorption is a process where organic substances (e.g., PFAS) present in a liquid are adsorbed on a solid (e.g., activated carbon granules) and consequently removed from the liquid. Activated carbon can be used in WTPs in two forms: granular activated carbon (GAC) or powder-activated carbon (PAC). There are major differences between these two applications, including carbon particle size, operational considerations, capital cost and PFAS removal effectiveness.

**PAC Is a Quick Solution for PFAS Adsorption but Comes With Operational Challenges**

In PFAS treatment applications, PAC is typically utilized for short-term, rapid PFAS treatment as a temporary reduction method before a permanent treatment method is selected. PAC adsorption is a well-known process used in drinking water applications for reducing total organic carbon (TOC) and compounds affecting color, taste and odor. PAC is an activated carbon fine powder with a small particle size range (<0.18 mm) that is added to water and mixed. After the powder is in contact with the desired water, it is removed prior to drinking water distribution. The ability of PAC to reduce contaminants depends on the type of PAC product, the PAC dose applied and the application point, the mixing efficiency, other constituents in water, and the contact time in water. Figure 1 shows PAC system equipment.
PAC can provide long-chain PFAS reduction, with higher PAC concentrations resulting in greater PFAS reduction.\textsuperscript{10} PAC has been shown to be less effective at removing short-chain PFAS.\textsuperscript{10,11} PFAS removal with PAC can vary greatly on a case-by-case basis and ranges from 40\% to 80\% removal. One benefit of using PAC is that PAC systems can be installed and integrated with existing WTPs relatively quickly. PAC can be added intermittently if occasional use is desired, such as to address seasonal fluctuations in certain contaminant levels. Additionally, some WTP already have PAC systems to remove additional contaminants such as TOC and color, taste and odor compounds, and thus are able to rapidly utilize PAC for PFAS reduction.\textsuperscript{9}

One challenge of PAC is that it may not effectively remove short-chain PFAS, and although it can remove additional contaminants, these contaminants will compete with PFAS for adsorption sites on the surface of PAC media. Therefore, the optimal PAC dose for PFAS removal may be uneconomically high. PAC also produces waste that requires disposal. After PAC has adsorbed PFAS, it is removed from water by other treatment processes and is disposed of with other solid wastes produced during water treatment. This poses two issues. First, the WTP will have to dispose of an increased amount of waste. Second, the waste now contains PFAS, which restricts where the waste can ultimately be disposed of. Depending on how the WTP manages the solid wastes, PAC waste may be conveyed to a wastewater treatment plant or landfill, which both pose challenges related to PFAS disposal and cycling of PFAS in the water system.

Due to these challenges, PAC is recommended as a short-term solution for PFAS reduction. Compared with other PFAS treatment methods discussed in this guide, PAC is a treatment option with low capital and operating costs, but operating costs depend on the PAC dose applied.
GAC Is Considered a Best-Available Technology for PFAS Removal and Provides Secondary Water Quality Benefits

GAC adsorption is an established water treatment process, often used for the removal of common contaminants such as TOC; color, taste and odor compounds; and constituents of emerging concern. GAC is similar to PAC in that they both remove constituents through adsorptive mechanisms and target contaminants must compete with other constituents for adsorption sites.

GAC media is larger in particle size than PAC (~1.0 to 1.6 mm), so GAC is loaded into vessels or filter boxes that allow water to pass through them. GAC can also be used in point-of-use applications in the form of filters attached to a faucet, refrigerator or pitcher, although results from different point-of-use applications vary significantly, and not all in-home filters are certified to remove PFAS. The NSF International website provides information about in-home filters. Figure 2 presents GAC filters used in WTP.

Figure 2 — GAC Filters (left: in vessels; right: in filter boxes)

GAC has proven its ability to reduce PFAS concentrations. Removal is highly dependent on PFAS properties, and GAC is more effective for long-chain PFAS removal when compared with short-chain PFAS. The presence of additional adsorptive compounds such as TOC or taste and odor compounds can inhibit PFAS removal by competing for adsorption sites. GAC has been reported to provide PFAS removal ranging from 66% to >99%, depending on the type of PFAS. Not all GACs are created equal; carbon manufacturers have worked to optimize GACs to target PFAS removal. As a result, GACs may vary in PFAS removal efficiency and life span until replacement is required. As with all other PFAS treatment options, removal efficiency should be validated with small-scale testing (referred to as pilot testing), as water quality and factors like contact time can also impact PFAS removal. Major benefits of using GAC are its reliability from a process standpoint, relatively low energy requirements and high PFAS removal.

A challenge of GAC is that it can be less effective for short-chain PFAS removal; however, validation at each site is recommended to verify removal. Another challenge with GAC is that as adsorption sites on GAC media become exhausted and PFAS removal decreases, GAC media must be replaced. GAC replacement may be driven by a number of factors, such as the targeted PFAS and other water quality constituents being treated and the targeted PFAS. To overcome this limitation, GAC is often added downstream of other
processes in PFAS applications to reduce the load of other compounds on the media, improving PFAS removal capabilities.

Also, the spent GAC media will contain adsorbed PFAS and must be disposed of properly. Spent media are often disposed of in landfills or sent to an incineration facility. Research is ongoing to characterize PFAS behavior in air emissions and to determine the conditions required for the destruction of PFAS during high-temperature incineration.

In addition, GAC units may need to be periodically cleaned by reversing flow through the filter — a process known as “backwashing.” Water used during backwashing requires disposal and may contain PFAS. WWTPs that would typically accept GAC backwash waste may be reluctant to receive this waste if PFAS are present.

Compared with other PFAS treatment methods, GAC requires **moderate capital and operating costs**. GAC can be a cost-effective PFAS removal alternative, but it is important to consider PFAS removal goals and influent water quality that may impact GAC’s ability to adsorb PFAS.

**Ion Exchange (IX) Is Considered a Best-Available Technology for PFAS Removal and Provides Secondary Water Quality Benefits**

IX is an established drinking water technology that utilizes anionic (negatively charged) or cationic (positively charged) resin beads to attract contaminants of interest from the water. Unlike PAC and GAC, which remove compounds through adsorption, IX exchanges one compound for another benign compound. Compounds that are removed leave the water and attach to the resin, while a harmless compound originally contained in the resin leaves the resin and enters the water. Anionic resins are most often used for water softening (e.g., removing calcium and magnesium) and to remove PFAS, TOC and/or color. PFAS-selective resin has been developed, although effectiveness varies for different types of PFAS, and research is ongoing. Figure 3 shows an IX vessel and IX resin beads.

**Figure 3 — IX Vessel (left) and IX Resin (right)**
PFAS reduction to below laboratory detection limits has been reported using IX, but removal is highly dependent on the presence and level of other contaminants in the water to be treated, the pH of the water, the contact time between water and resin, and the resin used.\textsuperscript{24–28} IX has been shown to provide long-chain PFAS and short-chain PFAS removal.\textsuperscript{18,20} In some studies, IX outperformed GAC for short-chain PFAS removal.\textsuperscript{29,30} There are several benefits to using IX, an efficient PFAS removal process for both long- and short-chain compounds with relatively low energy costs to operate. However, IX resins, like GAC, may have limitations when PFAS competes with other compounds for exchange on the resin. To overcome this limitation, IX is often added downstream of other processes in PFAS applications to reduce the load of other compounds on the resin, improving PFAS removal capabilities.

There are some additional challenges with using IX for PFAS reduction. Removal will decrease over time as PFAS consumes resin sites, prompting resin replacement.\textsuperscript{28} Another major challenge with IX is that resin will contain appreciable levels of PFAS and will require disposal once it has reached the end of its useful life. Resin is typically taken to a landfill or incinerated to destroy PFAS, but this can result in PFAS transferring from the resin to air emissions, which could recycle into the environment if not managed. Additional research is needed to develop test methods for PFAS in air emissions.

Compared with other PFAS treatment methods, IX has moderate capital and operating costs. IX resin is more expensive than GAC media, but less resin volume is required compared with GAC media at the same flow rate. IX can be a cost-effective solution to reduce PFAS, especially if short-chain PFAS removal is needed. The feasibility of ion exchange for PFAS removal should be evaluated at a pilot scale prior to full-scale implementation to ensure PFAS removal goals can be achieved.

Membrane Separation Provides the Greatest PFAS Removal but Comes With Additional Considerations and Costs

Nanofiltration (NF) and reverse osmosis (RO) are membrane filtration technologies that are established processes in the water industry. NF and RO filters are housed in membrane skids (i.e., a piece of equipment that can be rolled or moved). There can be several skids in use at a WTP for drinking water production. \textbf{Figure 4} presents both a membrane skid containing several hundred membrane elements and a single-membrane element. NF and RO technologies remove constituents by applying high pressures to push water through semipermeable membranes.\textsuperscript{31} Water that passes through the membranes is known as the “permeate” stream, and water that does not pass through is known as the “concentrate” stream.\textsuperscript{32}

RO membranes are less permeable compared with NF and therefore operate at higher pressures and remove more constituents. RO membranes are most often used to remove smaller, dissolved constituents such as sodium, chloride, and other total dissolved solids (TDS). NF is often employed to reduce larger compounds, including calcium and magnesium hardness, TOC, and color.\textsuperscript{31} Therefore, RO rather than NF membranes are typically selected for applications where dissolved constituent removal is an additional objective. In addition to use in WTPs, membrane systems can also be installed in homes as point-of-use technologies.
RO and NF are proven PFAS-removal technologies, with removal of short- and long-chain PFAS to below detection limits in a majority of studies, as expected given their proven ability to remove other organic constituents.\textsuperscript{11,14,15,20} In addition to significant short- and long-chain PFAS reduction, RO and NF can provide additional benefits, such as enhanced removal of other constituents in water, and PFAS do not compete for removal with these constituents, unlike in PAC, GAC and IX applications. Additionally, RO and NF systems have relatively small footprints.

Unlike IX and GAC processes, PFAS removal does not decrease over time in RO and NF applications; however, one challenge is that the membranes will clog over time and require cleaning. Wash water used for cleaning may need to be stored for additional PFAS treatment. Another challenge is that RO and NF processes require pretreatment to protect the membranes from damage and post-treatment to prevent corrosion in the distribution system.\textsuperscript{31} Pretreatment and post-treatment options can be costly to implement and maintain.

Disposal of the membrane concentrate stream is also a challenge. The concentrate stream typically contains two to six times the concentration of removed contaminants compared with the feed water and requires disposal.\textsuperscript{20,33} The presence of PFAS in the concentrate stream can make disposal challenging, although research evaluating concentrate treatment options has been performed.\textsuperscript{20,33} Concentrate disposal options include discharge to the sanitary sewer or a groundwater injection well or treatment at a concentrate treatment facility using a process like GAC or IX. It should be noted that if the wash water or concentrate is not treated to remove PFAS, it will recycle PFAS into the water system and not truly destroy PFAS.

RO and NF require high capital and operating costs compared with other PFAS reduction alternatives. These processes are energy intensive, which increases operating costs, and they require additional capital investments such as those for pretreatment and post-treatment.

**Established Drinking Water Treatment Methods Summary**

Each established drinking water treatment technology has benefits and limitations, and selecting the appropriate method depends on a multitude of variables, including the type of PFAS present and the concentration of other constituents, PFAS removal goals, and cost considerations. Table 1 presents a summary of treatment technologies, PFAS removal methods, PFAS removal effectiveness and relative costs. The capital and operating costs of these technologies is dependent on the size of the WTP. These
technologies generally range from several hundred thousand dollars to millions of dollars in capital cost, depending on the amount of water that needs to be treated.

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>PRIMARY PFAS REMOVAL METHOD</th>
<th>PFAS REMOVED</th>
<th>PFAS REMOVAL EFFECTIVENESS</th>
<th>RELATIVE COSTb</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC</td>
<td>Adsorption</td>
<td>Long-chain</td>
<td>&lt; 80%</td>
<td>$</td>
</tr>
<tr>
<td>GAC</td>
<td>Adsorption</td>
<td>Long-chain and partial short-chain</td>
<td>66% to &gt; 99%a</td>
<td>$$</td>
</tr>
<tr>
<td>IX</td>
<td>Compound exchange</td>
<td>Long-chain and short-chain, depending on the resin used</td>
<td>&gt; 99%a</td>
<td>$$</td>
</tr>
<tr>
<td>RO/NF</td>
<td>Separation or size exclusion</td>
<td>Long-chain and short-chain</td>
<td>90% to &gt; 99%</td>
<td>$$$</td>
</tr>
</tbody>
</table>

*aPFAS removal will decrease as GAC and IX operation continues, and GAC media or IX resin replacement will be required to achieve high removal rates again. bCost is highly dependent on the size of the treatment facility.

Promising New PFAS Treatment Methods Are in Development
There are several emerging and innovative methods for reducing PFAS in drinking water, including chemical oxidation, electrochemical oxidation, ozofractionation, sonolysis and novel sorbents. Some of the most promising ones are in the early stages of development and may be several years away from implementation. Many of these applications are being explored in laboratories and will require large-scale evaluation before they can be used in water treatment facilities. Scientists are exploring additional approaches and technologies for development.

Sonolysis uses sound waves to initiate chemical reactions in water and to promote chemical combustion, but the process is energy intensive.34 Ozofractionation, which uses a catalyzed reagent to aid in removal of PFAS, may be more feasible, but it generates a waste stream. Research shows that chemical oxidation removes PFOA but is less effective for other PFAS. Electrochemical oxidation destroys PFAS and doesn’t produce a waste stream but is less effective at reducing short-chain PFAS. Photochemical oxidation has shown mixed results for PFAS removal when compared with sonolysis and chemical oxidation.35 Novel sorbents have been used in soil remediation, and scientists are now exploring how they may be applied to drinking water treatment.36,37 Hydrothermal reaction can result in up to 80% removal of PFOS in concentrate streams.38 Last, plasma technologies can achieve moderate to high removal of PFAS, but plasma applications are limited and costly.39

Key Takeaways
PFAS cannot be removed by conventional water treatment technologies. Advanced treatment technologies exist, but they vary in their effectiveness in removing PFAS depending on the technology used, type of PFAS present and level of other water quality parameters. Key takeaways from this fact sheet include:
When selecting the appropriate technology, it is necessary to consider source water PFAS levels, treatment goals, capital costs, operational costs, current treatment technologies, changes to current operations and the presence of other water quality parameters.

Each advanced treatment option results in waste disposal challenges (e.g., sending to landfills or incineration facilities) that must be considered prior to selection, design and construction.

PAC is an activated carbon adsorption technology that can be added to existing WTP quickly at a relatively low capital cost, but it poses operational challenges that impact day-to-day operations and provides only partial PFAS removal. PAC is recommended for intermittent treatment until a permanent treatment technology (such as GAC, IX, NF or RO) is established.

GAC is a long-term activated carbon adsorption technology with greater PFAS removal than PAC. GAC can be designed and put in place in a matter of weeks or months, but the optimization may take months or years. GAC can provide significant, long-term PFAS removal at a moderate capital cost.

IX utilizes anionic resin beads to remove PFAS, and resins that are meant specifically to remove PFAS have been developed and are being further explored. Similar to GAC, IX systems must be designed and constructed. These systems come at a moderate capital cost, and optimization may take months or years, but they can significantly reduce PFAS in water.

NF and RO are membrane filtration technologies that provide excellent PFAS removal but result in operational changes, high capital costs, high operating costs and significant waste stream management issues.

All treatment technologies will require intense PFAS sampling and analysis to characterize performance, which will add additional costs for water quality testing.

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Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water

PFAS Risk Communications
What are Per- and Polyfluoroalkyl Substances (PFAS)?
Per- and polyfluoroalkyl substances (PFAS) are a class of thousands of synthetic organic chemicals designed for long-term stability, temperature resistance, friction reduction, and oil and water repellency. Often referred to as “forever chemicals,” nearly everyone has been exposed to these toxic substances. Not enough is known about the health impacts of most PFAS but they affect the immune, endocrine and metabolic systems at trace doses. Several of the most-researched compounds have been linked to health issues from cancers and increased cholesterol levels to preeclampsia during pregnancy.

Detected in drinking water and drinking water sources throughout the United States, the chemical properties of PFAS, such as the strength of the carbon-fluorine bonds, make them difficult to treat and remove using conventional water treatment processes. In the absence of enforceable federal regulations, several U.S. states have adopted or proposed drinking water standards for specific PFAS.

Uncertainties about the risk of different PFAS, the evolving science, and the variability among policies and standards pose a particular challenge when communicating with the public about PFAS. The purpose of this guide is to provide information on risk communication and public outreach strategies based on the best available evidence and additional resources.

Risk Communication for PFAS
Public communication about PFAS contamination is particularly challenging because much remains unknown about the thousands of PFAS, our toxicological understanding is rapidly changing, new PFAS continue to be identified, and state and federal guidance vary significantly. The multiplicity of sources and exposure pathways can create a sense that everything is equally contaminated and dangerous. Communicators need to help people understand the variability in the degree of contamination and relative risk. Conveying uncertainties early on and maintaining transparency as evidence emerges is critical to building and maintaining trust and successfully engaging the public in the decision-making process.

A science-based approach for communicating effectively in situations of high stress, concern, or controversy, risk communication can help address fears of the unknown and potential risks. Risk communication can help affected communities understand the processes of risk assessment and management, form perceptions of potential hazards, and participate in making decisions about how risks should be managed. Successful risk communication conveys information about risks in a relatable way to increase understanding and facilitate community participation in decision-making.

Ultimately, members of the public may not support and adopt proposed solutions to manage risk. For instance, there may be demands from the public to take action that is not technically or financially feasible, or uncertainty of human health impacts may lead people to oppose proposed action until a federal or state drinking water standard can be established. If people do not perceive a risk, they may not see a need to participate in necessary solutions. Risk communication can prepare the public to change their behavior or support solutions such as water treatment or remediation projects and understand that there may be insufficient scientific evidence to answer their concerns adequately.
Different levels of risk may require different response strategies.

Table 1 provides examples of theoretical situations with proposed government official or utility responses. These examples are provided as reference and should be customized for each situation based on the stakeholders, health impacts, and risk level.

**Table 1 – Theoretical PFAS Scenarios and Potential Risk Communication Response**

<table>
<thead>
<tr>
<th>Example 1: Industrial Discharger</th>
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</table>

**Issue:**
PFAS concentrations for two PFAS of concern are reported in multiple drinking water samples after a state sampling campaign to characterize water quality, however the levels are below federal and state PFAS guidance levels. A nearby industrial discharger is thought to be the source of the PFAS but has not been confirmed.

**Community Reaction:**
Community leaders are concerned about the reported PFAS levels and associated health risks. One public health advocacy group has advised the public not to drink tap water.

**Potential Response:**

*Leadership Efforts:*
- Assess the level of public health risk by discussing the potential health impacts from the current PFAS levels with state public health agencies. If necessary, release a “do not drink” health advisory for sensitive populations.
- Work with the state’s environmental department to conduct additional sampling to identify the source of contamination and range of levels.
- If potential health impacts are identified from a public health study, discuss water treatment options with the local drinking water utility to determine feasible methods for reduction of PFAS.
- Work with government officials to secure funding, if necessary, to support the efforts of health agencies and local utilities.

*Community Outreach:*
- Develop a public statement to share the results of the drinking water PFAS sampling and proposed next steps to mitigate the issue.
- Hold a public meeting with community interest groups (such as environmental advocates, community leaders) to share the current state of knowledge and listen to feedback and concerns.
- After the health risk is understood, disseminate information in the forms of press releases, social media, and town meetings to advise residents and obtain feedback.
### Example 2: Airport Firefighting

**Issue:**
A local university conducted and published a research study to quantify PFAS in drinking water treatment plant source waters (rivers and reservoirs) in the region and detected low levels of PFAS associated with aqueous film-forming foams (AFFF) used in firefighting. Further investigation determined that firefighting training at the airport was the source of the PFAS. The downstream drinking water treatment plants have not detected PFAS in their source or finished waters.

**Community Reaction:**
The published study sparked a news story that received several concerned citizen comments on social media. As a result, regional leaders have received emails asking for more information and associated risk level.

**Potential Response:**

**Leadership Efforts:**
- Work with the state’s environmental department to assess the need to conduct regular sampling at the drinking water treatment plant for an extended duration.
- Coordinate with airport officials to establish plans for phasing out and cleaning up PFAS onsite. Request alternative training methods or reduced training efforts to minimize PFAS discharges. This effort will likely need to be in coordination with the Federal Aviation Administration or the Department of Defense if it is a military installation.
- Work with legislators and other government officials to secure funding to support sampling, analysis and cleanup, as necessary.

**Community Outreach:**
- Communicate the plan for reducing or eliminating PFAS discharge from the airport source to the public and then the press. Utilize credible sources of information.
- Identify the key concerns of residents, then develop fact sheets or informational releases to discuss risks and reduce concerns related to drinking water. Identify concerns by talking with residents, reviewing social media, and soliciting questions from the public.
- Develop a webpage that includes educational materials and ongoing updates about progress towards mitigation.
Engaging the Community
An immediate goal of public communications should be to establish trust and prepare the community to participate in solutions. The purpose of communications should be to position a community to act and react effectively in difficult situations, more quickly accept reputable new information, and adapt as necessary.

PFAS risk communications should begin with an understanding of the community’s viewpoints and perception of the risk from PFAS. This involves consistent communication with community members and groups, such as public health interest groups, water treatment utilities, and environmental advocacy groups. A proactive strategy can uncover ways to build understanding, encourage adoption of solutions, change behavior, and alleviate fears and concerns. When people feel they have limited control, their sense of risk and outrage may be heightened. A collaborative atmosphere grants participants a greater sense of control.

COMMUNITY RESPONSES
- In Merrimack, New Hampshire, residents said that repeated changes in advisory levels and guidelines for providing households with bottled water undermined trust in state agencies and left them uncertain that the levels being set were actually protective of health.
- In East Bay Township, Michigan, people were upset that they were not notified when officials began testing for PFAS and residents only learned of contamination months later when testing results were publicly released.
- The EPA initially excluded representatives from community groups from its 2018 national summit on PFAS. The EPA had planned to engage with communities impacted by PFAS in the months following the summit, but community members who were eager for answers felt dismissed and excluded.

“There was a small amount of time set aside for feedback at public meetings, it was very time-limited. People were not involved in discussions, in setting the agenda, there was no seat at the table.”
Laurene Allen, Merrimack Citizens for Clean Water, Merrimack, New Hampshire

Developing Your PFAS Risk Communications Plan
Communication planning helps information reach your audiences in a timely, accurate, and understandable way. A PFAS Risk Communications Plan should be developed with core team members so individuals have an opportunity to contribute to the organization’s course of action. Consider these key elements for your risk communications plan:

Figure 1 - Risk Communications Plan Key Elements for Consideration
**Goals & Objectives**

Goals and objectives for PFAS communication efforts often focus on providing relevant and timely information to stakeholders and communicating the risk of impacts efficiently and accurately. If time permits, the risk communications team can facilitate workshops to determine communication goals and objectives for the type of PFAS situations that are most likely to arise. Once the goals and objectives have been identified, they can be paired with performance targets to guide improvements to your strategy over time. Here are some examples of relevant goals, objectives, and targets.

**Table 2 - Examples of PFAS Goals and Objectives**

<table>
<thead>
<tr>
<th><strong>Goal:</strong> Alert the public to detected PFAS contamination in the drinking water supply.</th>
<th><strong>Goal:</strong> Key stakeholder groups consider, discuss and support PFAS mitigation strategies.</th>
<th><strong>Goal:</strong> Collect community and stakeholder feedback and give community members a greater sense of control.</th>
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</thead>
<tbody>
<tr>
<td><strong>Objective:</strong> Work with local partners (utilities, universities, nonprofits, etc.) to make materials available that provide access to third-party information on PFAS health effects, disclose local PFAS monitoring results, and explain any action taken in response (or lack thereof). Include a way for the public to ask questions and raise concerns.</td>
<td><strong>Objective:</strong> Engage stakeholders and facilitate their participation in discussions. Request quarterly briefings from impacted utilities to obtain information about PFAS occurrence data, treatment and mitigation strategies and other actions since implementing the PFAS mitigation strategies to stay informed and equipped to share updates with constituents and the public.</td>
<td><strong>Objective:</strong> Partner with local utilities to “host” stakeholder meetings that allow for public feedback on acceptable costs, treatment level, and prevention strategies. Questions or concerns that cannot be answered should be documented and followed up on after the meeting.</td>
</tr>
<tr>
<td><strong>Target:</strong> The webpage is visited and answers people’s most common questions. Questions from the public are tracked and receive a response. Materials are updated based on feedback.</td>
<td><strong>Target:</strong> Constituents and impacted communities demonstrate active support for the strategies and approach.</td>
<td><strong>Target:</strong> Stakeholder meetings generate actionable insights that can be integrated into risk management strategy updates.</td>
</tr>
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</table>
PFAS Stakeholder Analysis

Stakeholder analysis identifies the people who need to receive information or provide input. The outcome will help shape effective messages and the selection of communication tactics that are meaningful to the key audiences and delivered where the audiences get their information.

Based on guidance from the International Association for Public Participation’s Spectrum of Public Participation (IAP2), stakeholders can be categorized based on their level of interest and level of influence to help identify needs for relationship and capacity building and determine how to target outreach. You may have different communication goals and strategies for each group.

Invest in building relationships with low-interest stakeholders or those who may not immediately express interest. Consider how to address affected groups who may not be participating in mitigation or preventative measures. Identify physical, psychological, sociological, and demographic characteristics of affected populations to help determine effective outreach methods.

In addition to affected populations, common PFAS stakeholders may include the following: Regional EPA representatives, state regulators, national and state legislators, city/town officials, water utilities, community groups, local businesses, environmental or public health advocacy groups, residents, industry groups, firefighters and emergency responders, and media and news outlets.

**Figure 2 - Stakeholder Analysis Communication Goals**

- **Engage**:
  - Low Influence, Low Interest: Provide balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions.
  - High Influence, Low Interest: Obtain feedback on analysis, alternatives and/or decisions.

- **Consult**:
  - Low Influence, High Interest: Work directly with them throughout the process to ensure that concerns and plans are consistently understood and considered.
  - High Influence, High Interest: Partner with them on each aspect of decisions including the development of alternatives and identification of the preferred solution.
Developing Key Messages
Key messages should inform, educate, and engage key audiences. They should give spokespeople, leaders, and other parties who speak on behalf of the community accurate and consistent information.

Start with the community and their concerns. Messages should convey what is known and unknown about PFAS and acknowledge uncertainty, include a commitment to share new information, and explain how decisions will be made to protect public health and remediate an identified PFAS contamination. It may be necessary to communicate how the relevant government agencies work and who has the authority to make various decisions.

Messages to the community should be tailored to the situation, clearly articulate the issues at hand, and state the steps that will be taken to resolve them. In the case of water quality risks, public safety should be a prominent message point. Messages should convey empathy, concern, commitment, and action.

Sample PFAS Messages

- PFAS are highly persistent chemicals that have been widely used for decades in industrial applications, household and consumer products, food packaging, and firefighting foams.
- Your health and safety are our priority. PFAS are not a federally regulated drinking water contaminant, but our goal is to protect everyone’s health [and not exceed health advisory levels or state standards, as applicable].
- Our scientific understanding of PFAS is evolving, the scientific community is rapidly recognizing the environmental and health effects of PFAS. Research on health effects from PFAS exposure is ongoing.
- We are actively working to obtain more information about PFAS in our community as quickly as possible. Additional testing is ongoing, which will help us answer more questions and determine next steps.
- We are committed to transparency, and we will share new information about PFAS as it becomes available. Stay updated by visiting [website or agency]
- We monitor for PFAS in our drinking water on a regular basis. Our level is typically [X], which is [lower/higher] than the [federal health advisory level/state standard].
  - If you have high PFAS concentrations (either perceived by a stakeholder group or above state or federal guidance), be prepared to explain planned or in-progress abatement actions.
Tools and Tactics
Informative, timely, and concise communication is essential for building awareness, understanding, and trust among affected populations and key stakeholders. To reach audiences effectively, develop and implement tools that directly support the goals and objectives in the communications plan. Evaluate whether the tools and tactics are sufficient to engage diverse groups, particularly low-interest affected populations. Materials should be available in multiple languages and accessible to those with disabilities. Figure 1 and Table 2 provide examples of communication tools for community outreach.

Figure 1 - Example of Communication Tools (Online Interactive Map, Illustrations, Community Meetings)

Michigan PFAS site map and cycle illustration by the Michigan Department of Environment, Great Lakes, and Energy (EGLE); EPA roundtable meeting to discuss PFAS pollution in Michigan, October 5, 2018, courtesy of Bryce Huffman / Michigan Radio.
# Table 2 - Examples of Tools and Tactics

<table>
<thead>
<tr>
<th>EXAMPLE TOOLS AND TACTICS</th>
<th>WEBPAGE</th>
<th>PUBLIC MEETINGS</th>
<th>ONLINE MEETINGS</th>
<th>POP-UP EVENTS</th>
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<tbody>
<tr>
<td><strong>WEBPAGE</strong></td>
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<tr>
<td>Webpages dedicated to PFAS issues in your community (available in multiple languages, as appropriate) can serve as the public’s go-to source for accurate information, materials, and updates.</td>
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<td>Incorporate images and infographics with short sentences to make information accessible.</td>
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<td><strong>PUBLIC MEETINGS</strong></td>
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<td>Well-planned public meetings can provide structured opportunities for the community to ask questions, speak to subject matter experts, and offer feedback. A public meeting may not be an ideal place to explain risk or reduce outrage.</td>
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<td>Planning public meetings at venues on bus routes or locations that can be accessed by public transit can make it easier to attend for those who may not have transportation.</td>
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<td><strong>ONLINE MEETINGS</strong></td>
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<tr>
<td>Online meetings can also be an interactive format. Recordings of online meetings can be available on-demand 24/7, which is convenient for stakeholders who are unavailable during traditional public meeting hours or unable to travel.</td>
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<td>This approach is also an ideal way to extend your reach to members of the public who may not have an interest in attending an in-person meeting, especially if it is hosted by a government entity.</td>
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<tr>
<td><strong>POP-UP EVENTS</strong></td>
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<tr>
<td>Setting up an informational booth or display in community gathering spots and events can engage a more diverse group of people, including low-interest groups, underresourced communities, or those who are not being reached through other means.</td>
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<td>Pop-up meetings allow you to be proactive and go to the community and connect with people who may not seek out information on the topic.</td>
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<td><strong>SOCIAL MEDIA</strong></td>
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<tr>
<td>Social media can be used to share messages at any level of risk. Compelling imagery, targeting specific feeds, and geographically targeted advertising can help to hone message delivery and to reach diverse or hard to reach communities.</td>
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<td><strong>INFORMATIONAL BROCHURES</strong></td>
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<tr>
<td>A visually-compelling brochure can improve information retention after in-person events or be distributed by community partners.</td>
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<tr>
<td><strong>EDUCATIONAL VIDEOS</strong></td>
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<td>Video promotes high levels of information retention through an approachable, familiar medium, making it an effective, versatile tool for sharing information and calibrating people’s understanding of risk. This tool is also a good means for reaching diverse and underserved communities.</td>
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<tr>
<td><strong>MEDIA OUTREACH</strong></td>
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<tr>
<td>Local news media outlets are a powerful channel for fact validation and storytelling. Good relationships with local reporters, proactive news releases and advisories, and consistent fact-based talking points can promote accurate reporting.</td>
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<tr>
<td>Be sure to share information with affected people and communities first.</td>
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</table>
Performance Metrics and Reporting
Measuring and monitoring success of communications will provide insight on which tools, tactics, and messages work and which need to be reworked. Track attendance to see which formats, times, venues etc. permit different audiences to participate. Identify any groups who are not being reached or participating. Incorporating tools like website analytics, social media engagement statistics, reach metrics, and focus group feedback into your regular communication plan updates will provide valuable data for adapting a communications plan. Examples include a PFAS webpage with links to good external resources and real-time data updates, PFAS fact sheets with frequently-asked questions, materials available in multiple languages, social media posts with relevant PFAS updates, and meeting minutes from online or public meetings.

Responding Reactively
Organizations may need to respond reactively to news of PFAS contamination, for instance, when tests conducted by independent groups (such as universities or environmental interest groups) identify a potential problem. When this happens, many of the steps for proactive communication still apply. Consider these steps in a crisis situation:

Figure 3 - Steps to Responding Reactively

1. Assess what happened.
2. Determine the risk and assign roles and responsibilities.
3. Draft and approve an interim public statement to use for immediate response.
4. Prepare internal stakeholders and spokesman with key messages.
5. Consider the time, resources, and costs needed to meet crisis communications goals.
6. Draft and implement a communications action plan specific to the situation.
7. Monitor the situation and report on outcomes. Update your strategy accordingly.
8. Assess ongoing risk until the situation has been resolved.
9. Record lessons learned while the situation is still fresh.
Additional Resources
As part of its technical resources for addressing PFAS, the Interstate Technology & Regulatory Council (ITRC) published materials on [PFAS risk communication](https://pfas1.itrcweb.org/14-risk-communication/) and a training video that provide more information on the topics covered here. The Association of State and Territorial Health officials (ASTHO) and the Environmental Council of the States (ECOS) developed an [online hub of PFAS risk communication resources](https://www.astho.org/PFAS/) that includes FAQs for the public, clinicians, legislators and the media as well as communications case studies from a number of states. The [National PFAS Contamination Coalition](https://www.astho.org/PFAS/) was formed in 2017 to connect and support community groups, it represents local activists with years of experience confronting PFAS contamination.

Key Takeaways
Risk communications is fundamental to successfully engaging the public to respond to potential issues and public concern. When done well, it can strengthen your reputation as a trusted source and reduce concerns when communicating about risks.

- Successful risk communications can help reduce fear and prepare people to participate in solutions.
- Assess knowledge and sentiment of the public before developing a communication plan.
- The primary purpose of public meetings should be engagement with community members and creating a collaborative atmosphere. Provide structured opportunities for the public to offer feedback and ask questions.
- Make an effort to acknowledge and understand stakeholder concerns, be careful to not dismiss concerns.
- Conveying uncertainties and maintaining transparency as evidence emerges are critical to building and maintaining trust and successfully engaging the public.
- Always assess level of risk in order to plan or respond accordingly.
- A communications plan will help in both proactive and reactive situations.
- Understand stakeholders based on levels of interest and influence, and opportunities to engage and increase interest.
- Communications are not one-size-fits-all. Tailor messages and tools to reach different audiences.
- Assess whether you are engaging all affected communities and employ a variety of tactics and tools to do so.
- Tools and tactics for communication with particular groups should align with well-defined goals and objectives, which should be measured and monitored.

References
## Relevant Key Words and Definitions

<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITION</th>
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<tbody>
<tr>
<td>Adsorption</td>
<td>The process by which molecules are attached to the surface of a solid particle.</td>
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<tr>
<td>Bioaccumulation</td>
<td>The gradual accumulation of a substance (or substances) in an organism.</td>
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<tr>
<td>Biodegradable</td>
<td>Capable of decomposition by bacteria or other living organisms.</td>
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<tr>
<td>Constituents of emerging concern (CEC)</td>
<td>A group of compounds that have been recently detected in water and may pose negative effects on public health or the environment. This includes pharmaceuticals, personal care products, industrial chemicals and endocrine disruptors.</td>
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<tr>
<td>Distribution system</td>
<td>Part of the water supply network where potable water (finished water treated at drinking water treatment plants) is distributed to the community through a series of residential, commercial and industrial service pipes.</td>
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<td>Granular activated carbon (GAC)</td>
<td>A form of particulate carbon (medium) manufactured to adsorb soluble contaminants such as organics and PFAS. This product has high surface area per unit mass and the ability to capture a large variety of contaminants. Compared with PAC, GAC uses large carbon particles and is considered a permanent and robust treatment method for long-term contaminant removal.</td>
</tr>
<tr>
<td>Groundwater well</td>
<td>A well drilled into the ground to access underground water supplies referred to as aquifers. Some of these systems may have treatment systems in place in the well to remove fine particles like sand that can clog the well pipe.</td>
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<tr>
<td>Half-life</td>
<td>The time required for a quantity to reduce to half of its initial value in the environment or inside plants, animals or humans.</td>
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<tr>
<td>Influent</td>
<td>Water entering the treatment plant or process being discussed (a tank, treatment scenario, watershed, etc.).</td>
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<tr>
<td>Ion exchange (IX)</td>
<td>A water treatment process by which one or more contaminants is removed from water by exchange with another substance embedded in a manufactured resin.</td>
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<tr>
<td>Intake</td>
<td>A location where a drinking water treatment plant draws water from source water (usually a reservoir). This point is located at the beginning of the drinking water treatment plant process, prior to treatment.</td>
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<tr>
<td>Relevant Key Words and Definitions</td>
<td>AAAS EPI Center</td>
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<p>| Long-chain PFAS | PFAS that have a sulfonic acid functional group (made up of sulfur, oxygen and hydrogen atoms — SO$_3$H) and contain six or more carbons, or those that have a carboxylic acid functional group (made up of carbon, oxygen and hydrogen atoms — COOH) and contain eight or more carbons. |
| Nanofiltration (NF) | A membrane filtration method that uses nanometer-sized pores to filter water from a multitude of contaminants, such as organic matter, out of water. |
| Organic matter | A complex mixture of organic compounds that are found in surface water and groundwater. Types of organic matter are tracked in drinking water applications as surrogates for treatability of contaminants, operational efficiency and overall water quality. |
| Outfall | A place where a river, drain or sewer empties into the sea, a river or a lake. |
| Per- and polyfluoroalkyl substances (PFAS) | A class of thousands of man-made compounds that contain within their molecular structure a chain of carbon atoms in which one or more of the carbon atoms is “perfluorinated,” meaning that other than its carbon-atom neighbors, it is bonded only to fluorine atoms (e.g., perfluorooctanesulfonic acid or C$<em>8$HF$</em>{17}$O$_3$S). |
| Persistence | Length of time a chemical exists in the environment before being destroyed or transformed by natural processes. |
| Powder-activated carbon (PAC) | A form of powdered or pulverized carbon manufactured to adsorb soluble contaminants such as organics and PFAS. This product has high surface area per unit mass and the ability to capture a large variety of contaminants. Compared with GAC, PAC uses smaller carbon particles and is considered a short-term treatment option for rapid and sometimes intermittent operation. |
| Precursor | A compound that can react or degrade (via biodegradation or environmental degradation) to produce another compound. |
| Primary source | The source that directly contributes PFAS to the environment (e.g., industrial dischargers, airfields using firefighting foam containing PFAS). |
| Raw water (also referred to as source water) | The untreated water source (usually groundwater or a surface water source such as a reservoir) that is withdrawn for treatment at a drinking water treatment plant. |
| Reference dose | An estimate of a daily exposure to the human population that is likely to be without appreciable risk of adverse health effects over a lifetime. |
| Reverse osmosis (RO) | A membrane filtration method that uses osmotic pressure to direct water to pass through a membrane and separate out a multitude of contaminants, such as salts. |</p>
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<th><strong>Secondary source</strong></th>
<th>A source that indirectly contributes PFAS to the environment through conveyance of PFAS from primary sources (e.g., wastewater treatment plant effluent, landfill leachate).</th>
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<tbody>
<tr>
<td><strong>Short-chain PFAS</strong></td>
<td>PFAS that have a sulfonic acid functional group and five or fewer carbons, or those with a carboxylic acid functional group and seven or fewer carbons.</td>
</tr>
<tr>
<td><strong>Total organic carbon (TOC)</strong></td>
<td>A measure of the amount of organic carbon found in a water sample, often used as a nonspecific indicator of water quality.</td>
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<tr>
<td><strong>Toxicity</strong></td>
<td>The quality of being toxic and imparting an adverse health impact after exposure.</td>
</tr>
<tr>
<td><strong>Utility</strong></td>
<td>An organization supplying the community with electricity, gas, water or sewerage treatment.</td>
</tr>
</tbody>
</table>
The Center for Scientific Evidence in Public Issues (AAAS EPI Center) is an initiative of the American Association for the Advancement of Science (AAAS) designed to deliver clear, concise and actionable scientific evidence to policymakers and other decision-makers. The AAAS EPI Center synthesizes and distills scientific evidence on key societal issues in a way that makes it clear how that evidence can inform policymaking and decisions at the local, state and federal levels. We make it easier for people to access relevant scientific evidence and expertise. AAAS is the world’s largest general scientific society, with nearly 250 affiliated societies and academies of science, and is the publisher of the Science family of journals.