The Science and Policy of PFASs in the Great Lakes Region

A ROADMAP FOR LOCAL, STATE AND FEDERAL ACTION

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Executive Summary

The Great Lakes region is potentially facing one of the most serious threats from a family of toxic chemicals in recent memory—per- and polyfluoroalkyl substances (PFASs). These chemicals are used in baby products—baby mats, pads, blankets, and bibs. They are also used in outdoor clothing, including rain jackets, snowsuits and winter gloves, as well as in bed linens, carpets, footwear, non-stick pots and pans, toothpaste and dental floss, and other personal care products. PFASs are also used extensively in firefighting foam, with use at military bases, airports, and petroleum refineries. In addition, the chemicals have been found in all parts of the environment, from soil, water and air to fish and wildlife, and from the Great Lakes to the Arctic. The widespread occurrence of PFASs in the environment and potential health effects serve as an urgent warning that society must confront this threat to protect the health of people and wildlife. The good news is that local, state, and federal governments have tools at their disposal to advance manageable solutions to this far-ranging problem. But they must act with urgency and purpose. Federal action to address the problem has been slow-going. Some members of Congress are taking steps to advance solutions to the PFAS crisis. Yet questions remain whether a divided Congress and ambivalent White House will act quickly and aggressively enough to address the scope of the problem. For this reason it is important that governors and state legislatures take a leadership role in confronting the PFAS crisis to protect public health, fish and wildlife, and the economy in the region. Delay will only make the problem worse and more costly to solve. This report reviews the science around PFASs in the Great Lakes—including their sources, presence in the environment and people, and wildlife and human health risks—as well as the policy and legal framework to address them, and identifies a number of recommendations for tackling the problem in the region, with an emphasis on Great Lakes states.

PFASs include over 4,000 organic compounds, although approximately 1,200 were historically produced in the United States. Many of the compounds are persistent, bioaccumulative, and toxic, and these characteristics contribute to their presence throughout much of the Great Lakes region as well as ecological and human health concerns. Although a number of studies have reported levels of different PFASs in fish and wildlife in the region, there has been much less work on the chemicals' effects. Studies on tree swallows in the Upper Midwest found an association between reproductive impacts and PFAS exposures, and the concern to date appears to be greatest where PFAS exposures occur with other contaminants.

People can be exposed to PFASs through multiple routes, including drinking water, food (including fish), and directly from consumer products, though multiple studies have identified food ingestion (and to a lesser extent drinking water) as particularly important. There have been relatively few studies on human PFAS exposures in the Great Lakes region, though one study of male anglers in Wisconsin found blood PFAS levels were associated with increased local fish consumption. Documented health effects of PFASs include increased risk of kidney and testicular cancers in more highly exposed groups, impacts on the immune system, and impacts to metabolism, including elevated total cholesterol. There has been very limited study on disproportionate exposures to PFASs in low-income communities and communities of color, though one study reported higher exposures for two PFASs in middle aged African-American women compared to white women in southeastern Michigan.

Concerning improving scientific understanding of PFASs and its application in the region, this report has multiple recommendations, with several key recommendations (which may involve states working with federal, local, academic, and other partners) including the following:

- Develop comprehensive inventories of sources of PFASs in the region, ranging from manufacturing to use to disposal stage, and support PFAS listing and reporting via the U.S. Toxics Release Inventory.
- Develop a better understanding of environmental cycling of PFASs in the region through consideration of information on sources, modeling and measurement assessments, potentially with a geographic focus (e.g., through a mass balance study).
- Develop a framework for identifying priority monitoring needs in the Great Lakes environment, expand monitoring (including for fish and wildlife) in a comprehensive but systematic manner, and include reporting as part of the State of the Great Lakes reports.
- Support studies on potential PFAS impacts to wildlife in the region, including a broader suite of bird, reptile and amphibian, and mammalian species at risk.
- Increase understanding of human exposures and potential effects from PFASs through support for laboratory animal and epidemiological studies, as well

as broader but targeted biomonitoring, including considering susceptible populations.

- Initiate or expand, as appropriate, incorporation of PFASs into fish contaminant advisory programs, including considering implications of exposures to multiple PFASs as well as other contaminants.

Concerning policies and legal programs to address PFASs in the Great Lakes region, this assessment focused on efforts on the U.S. side. Because many federal laws delegate authority to the states to implement key programs, the recommendations highlight how states can be leaders in tackling PFASs. This work can occur through several key federal laws that provide tools to states for addressing toxic chemicals such as PFASs. This report includes multiple policy and legal recommendations, and key recommendations for implementing programs through those laws include the following.

Clean Water Act Recommendations

- States should develop numeric water quality criteria for PFASs of concern.
- States should include in National Pollutant Discharge Elimination System (NPDES) permits effluent limits and monitoring requirements for PFASs.
- States should ensure that permits incorporate technology-based effluent limits and water quality-based effluent limits for PFASs as appropriate.
- State agencies should include monitoring requirements where PFASs of concern are expected to be present in influent waters.
- Public wastewater treatment plants should require pretreatment of PFAS through development of local limits.
- In issuing Clean Water Act permits to public wastewater treatment plants, states should require monitoring of PFAS in biosolids, and where necessary should ensure that disposal or land application is done so as to protect human health and environment.

Cleanup laws (including the Comprehensive Environmental Response, Compensation and Liability Act and the chemical production law (Toxic Substances Control Act))

- States should designate PFASs of concern as hazardous for purposes of their cleanup laws, and should develop enforceable cleanup criteria.
- States should urge EPA to aggressively implement programs under the Toxic Substances Control Act involving PFASs, including regarding significant new use rules regarding testing requirements, reporting and other aspects of PFAS production and use.

Safe Drinking Water Act

- States should develop enforceable, protective PFAS drinking water standards for public water systems.
- States should amend applicable laws and policies that govern drinking water revolving fund allocations and other financing mechanisms to ensure that water systems in vulnerable communities can afford to upgrade treatment technology and otherwise implement new PFAS requirements.

Binational/International Agreements

- The U.S. Environmental Protection Agency and Environment and Climate Change Canada should adopt an aggressive binational strategy addressing multiple PFASs in the region, through Annex 3 of the Great Lakes Water Quality Agreement
- Both Canada and the United States should implement policies consistent with requirements in the Stockholm Convention on Persistent Organic Pollutants (even though the United States has yet to ratify the treaty), including promoting international initiatives to reduce the global uses, trade, and releases of PFASs, including regarding PFAS-containing products.

Wielding and deploying policy tools such as the Clean Water Act to ratchet up protections for drinking water supplies need to go hand in hand with robust financial investments to upgrade and modernize water infrastructure. In this endeavor, the federal government needs to step up to the plate to help communities in the Great Lakes region and across the country deal with the serious threat posed by this group of toxic chemicals. States and local communities cannot go it alone. Indeed, at a time when many communities are struggling to maintain their water infrastructure to meet their clean water goals, the federal government can provide much-needed assistance in advancing solutions that work for urban and rural communities alike, including communities with potential disproportionate exposures to PFASs. Combined efforts by the communities, states, and the federal government will be needed to address the PFAS problem, and ensure the health of people and wildlife in the Great Lakes region.

Introduction

The Great Lakes have been subject to threats from toxic chemicals for decades. Chemicals such as polychlorinated biphenyls (PCBs) and mercury are still responsible for numerous fish consumption advisories throughout the Basin, despite progress that has been made in addressing multiple sources or reservoirs of the chemicals through the years. In addition to these chemicals of longstanding concern, there is increasing attention from the scientific community, nongovernmental organizations (NGOs), industry, and government in addressing so-called chemicals of emerging concern (CEC), or chemicals either new on the market or for which there is increasing scientific understanding of threats to human health and/or the environment.

One such group of chemicals is per- and polyfluoroalkyl substances (PFASs).[1] These chemicals pose concerns given both historic and current widespread uses in a number of applications of thousands of related compounds; the persistent, bioaccumulative and toxic nature of many of the compounds; and potential human health and ecological concerns. Scientific understanding has been advancing rapidly in the past decade around multiple aspects of the PFAS issue, including concerning levels in the environment, human exposures and potential effects, and ecological exposures and potential effects.

As in other locations, there are concerns about the presence and potential effects of PFASs in the Great Lakes Basin. The Great Lakes themselves are the source of drinking water for approximately 40 million people,[2] and many millions more within the basin obtain drinking water from other surface waters and groundwater. In addition, the Great Lakes support significant biodiversity, including historically up to 180 fish species and other diverse life, and diverse habitats including large freshwater estuaries, offshore rocky reefs, coastal wetlands, shoreline dunes, and other habitats.[3] The Great Lakes region is home to diverse peoples, including many Tribes and First Nations, and supports significant Tribal/First Nation, commercial and recreational fisheries, valued at over $7 billion annually.[4] Though PFASs have been in production for decades, increasing development of fish consumption advisories means PFASs will join mercury, PCBs, and other contaminants in negatively affecting this important ecosystem service.

In addition to the increasing research on environmental levels and potential effects in fish, wildlife, and humans, PFASs have been the subject of increasing attention by the policy community, including government at state, provincial, federal, binational, and international levels. The multiple jurisdictions involved in Great Lakes governance offers both opportunities and challenges in responding to the threats from PFAS chemicals in the basin. Indeed over $3 billion has been spent through the U.S. Great Lakes Restoration Initiative (GLRI) to address multiple threats (including toxic chemicals) to the Great Lakes, with the U.S. Environmental Protection Agency (U.S. EPA) and 13 other federal agencies and all eight Great Lakes states involved in restoration efforts. It is important that ongoing risks from chemicals such as PFASs not threaten this restoration program (or a complementary program on the Canadian side).

The objectives of this report are two-fold:

- Review the science around PFASs in the Great Lakes, with an emphasis on what is known about uses and sources, cycling in the environment, exposures and effects in fish and wildlife and people, and identify any clear research needs, in particular to better inform management;
- Review the current policy and legal framework in place in the region capable of addressing PFASs, and identify near-term opportunities and policy needs to better address the threats from these chemicals in the Basin.

PFAS foam in Van Ettan Lake. Photo credit: Michigan Department of Environmental Quality.

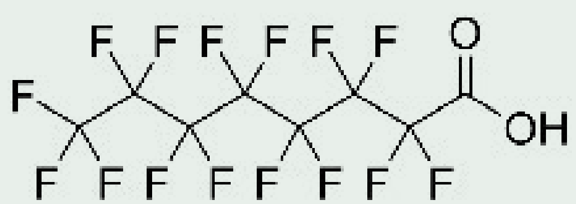
Review of State of Science Around PFASs in the Great Lakes Region

Understanding the risks from PFASs in the Great Lakes region and developing management approaches can be informed through several avenues, including consideration of the characteristics and sources of PFASs (including via uses and releases), environmental cycling (how the chemicals behave in the environment), ecological exposures (extent to which an organism is taking up the chemicals), ecological effects (on particular organisms) as well as potential human exposures and effects. This section briefly reviews available information on these components.

Characteristics and Uses of PFASs

Per- and polyfluoroalkyl substances are a family of over 4,000 related organic compounds.[5] They consist of linked carbon atoms as the backbone, with fluorine atoms replacing some ("polyfluoro") or all ("perfluoro") of the hydrogens that might otherwise be present. Two of the more commonly used PFAS compounds in the United States historically are perfluorooctanoic acid (PFOA, see chemical structure in Figure 1) and perfluorooctane sulfonic acid (PFOS), which are, respectively, part of the larger perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs) classes of compounds.[6] See Appendix for naming conventions for PFASs covered in this report.

FIGURE 1. Chemical structure of an example PFAS compound, perfluorooctanoic acid (PFOA)



Source: Edgar181-Wikimedia

In part because of the strong carbon-fluorine bonds, the compounds are not degraded easily, which has made them useful in various industrial and consumer product applications (see next section). However, this characteristic also means they can be very persistent in the environment. In addition, many of them have a tendency to be taken up by organisms in the environment (bioaccumulate). Moreover, many PFASs are toxic to either organisms in the wild or to people at relatively low levels. Chemicals with these characteristics—persistence, bioaccumulation potential, and toxicity—are termed PBT chemicals, which also includes some chemicals of longstanding concern such as PCBs and DDT.

One important distinction of many PFASs is that rather than having an overall nonpolar structure like PCBs (which do not mix well with water), they instead have a nonpolar section on one end (the carbon chain on the left portion of the molecule in Figure 1) and a polar section on the other (the "head" group on the right portion of the molecule), characteristics important regarding potential uses. For PFAS chemicals with such a structure, the polar portion of the molecule indicates those compounds will generally be more soluble in water than they otherwise would be (i.e., a greater tendency to remain in water rather than bind to soil, sediment, or specific locations in organisms). Thus, at a spill site, PFASs are more likely to be transported in soil and groundwater, rather than bind quickly and be retained by soil particles (as would be the case with chemicals such as PCBs). This makes containment and cleanup a much more challenging and difficult task, including due to their decades of use. A further challenge with PFASs is the potential for individual "precursor" compounds to be transformed in the environment to related chemicals, many of which may be toxic and persistent. For example some of the PFASs (such as fluorotelomer alcohols) can degrade to PFOA.[7]

PFASs have been used in multiple products and applications since they were first invented and then produced and marketed beginning in the 1940s, ranging from consumer products to industrial applications to fire-fighting foam (see Table 1). Many PFASs are used as surfactants (chemicals that can interact with both water and organic phases, as noted above), given the combined polar and nonpolar portions of the molecule. Some PFAS chemicals can function as surface protectors, for example preventing water from penetrating jackets or footwear. An example of a complex use category for PFASs is pesticides, where the pesticide sulfluramid can include PFAS compounds as impurities produced during the manufacturing process, but can also break down into PFAS compounds (in particular PFOA and PFOS) in the environment.[8]

Although over 4,000 PFAS compounds have been identified as potentially manufactured and used globally, the most recent information from the U.S. EPA indicates approximately 600 PFAS compounds as currently in use in the United States with another 600 formerly in use but now off the market.[9]

TABLE 1. Examples of Products That May Contain PFASs

CATEGORY	EXAMPLE PRODUCTS
Clothing	*Outdoor jackets, rainsuits, snowsuits, winter gloves*
Children's/baby products	*Baby mats, pads blankets; bibs; outdoor jackets, rainsuits*
Other water-repellent products	*Carpet, footwear*
Home furnishings	*Bed linens*
Cookware	*Non-stick cookware*
Food-contact packaging	*Some grease-resistant papers, microwaveable popcorn bags*
Other liquid consumer products	*Polishes, waxes, paints*
Personal care products	*Toothpaste, shampoo*
Fire-fighting foam	*Aqueous film-forming foams*
Pesticides	*Sulfluramid*
Chemical production or utilizing facilities	*Chromium electroplating, electronics manufacturing*

Sources: CEC, 2018[10]; ITRC, 2017[11]; U.S. EPA, 2019a[12].

Because of limited reporting requirements, it is not always clear which products may contain PFASs, including specific PFASs and in what amounts. A recent study examined 194 liquid products and screened for 41 PFASs, finding 24 individual PFAS compounds detected in 55 percent of samples, with most PFASs detected in aqueous film-forming foams (AFFF, used in firefighting foam) and in impregnating agents (such as fabric protector sprays).[13]

Though currently there is significant attention by policy-makers, researchers, and the public to PFASs, policies and programs addressing the chemicals began two decades ago in the United States. A voluntary manufacturing phase-out of PFOS was carried out through an agreement in 2000 by manufacturing company 3M and U.S. EPA, and in 2006, U.S. EPA began implementing with manufacturers a PFOA Stewardship Program.[14] However, to date, though rules have been adopted, given challenges in formally banning chemicals in general (in particular under the previous law), no PFASs have been formally banned under the federal toxic chemicals law (see further discussion in the State Policy Tools to Address PFAS Impacts to Water Quality section on page 21). At the same time, there has been a general movement among manufacturers from "long-chain" PFASs (such as PFOS and PFOA) to "short-chain" compounds.[15]

Sources of PFASs Relevant to the Great Lakes Region

Like many other persistent organic pollutants (or POPs), there can be many sources of PFASs to the environment. These can include facilities manufacturing the chemicals, facilities producing products using the chemicals, products during their use stage, and any material during the waste/disposal stage. In addition, wastewater treatment plants receiving influent from industrial, commercial, or residential customers can also release PFASs, whether in the wastewater effluent, or with the disposal of solids (dried sludge). Given the many PFAS chemicals historically or currently in use as well as the plethora of products and processes potentially entailing use of PFASs, developing a comprehensive assessment of sources of PFASs to the environment is challenging.

Several studies have developed estimates of PFAS releases to the environment, including studies on global production and releases. For example, one study estimated emissions of the class PFCAs from 1951—2015 at 2,610—21,400 tons, with a slowdown and then increase in production after 2002. In addition, the researchers indicated a general shift since 2002 in production (especially fluoropolymer production) from North America, Europe, and Japan to emerging economies in Asia, in particular China.[16] An earlier study noted that a substantial portion of PFOS releases historically was through the manufacture and use of another PFAS, perfluorooctane sulfonyl fluoride, with up to 2,700 tons PFOS entering wastewater streams globally, following losses from stain-repellent carpets, firefighting foams, and other products.[17]

A recent study in central and eastern China considering both air emissions and water discharges found the majority of PFOA/PFOS releases to the environment was via direct discharges of wastewater, whether from industries or municipal wastewater treatment plants. The other major sources for PFOS were firefighting foam and pesticide application (in particular sulfluramid).[18] Note that though widely used in certain countries, sulfluramid has limited use in the United States in termite control.[19] A study measuring selected PFAS compounds at 37 sites in the northeastern United States reported generally higher concentrations for most PFASs in urban areas, and based on statistical analysis, inferred that major sources were airports and textile mills, atmospheric emissions from the waste sector, and the metal smelting industry.[20]

Concerning tracking chemical releases in general in the United States, one principal database is the Toxics Release Inventory, in which U.S. EPA (under authority of the Emergency Planning and Community Right-To-Know Act) compiles self-reported estimates from certain industries of releases of particular chemicals into air, water, land disposal, and underground injection. However, to date, individual PFAS chemicals are not among the more than 600 chemicals for which reporting is required.[21] An additional inventory managed by U.S. EPA is the National Emissions Inventory, which includes estimates of air emissions for many toxic chemicals by multiple industries, and which is published every three years, though does not currently include any PFAS chemicals.[22] In a 2011 review report, Michigan agency staff identified a number of potential sources of PFASs to the environment as of 2008, which included over 100 individual sources, including chrome platers and polishers (facilities using an electrochemical process to apply chromium to metal surfaces for various applications), sewage sludge incinerators, municipal waste incinerators, and airports, both civilian and military (current or former installations).[23] We are not aware of any comprehensive inventory of PFAS releases to the environment available for any Great Lakes state, though Michigan (through the Michigan PFAS Action Response Team, or MPART) is assessing releases from multiple sectors.[24]

Environmental Cycling of PFASs

Assessing potential exposures of organisms in the environment and people to PFASs entails understanding the cycling of PFASs, from uses and sources to various environmental media, including air, water, soil and biota

DEQ geologist investigates steel drums for potential PFAS contamination. Photo credit: Michigan Department of Environmental Quality.

such as fish. As part of this understanding, measurements of the various media are needed. This section briefly reviews environmental cycling and approaches to measuring PFASs in the Great Lakes environment.

OVERVIEW OF ENVIRONMENTAL CYCLING OF PFAS

Because they are persistent organic pollutants and have a wide range of physical-chemical properties, PFAS cycling in the environment can be complex. A schematic of the potential pathways from PFAS sources to various environmental compartments is provided in the infographic on p. 24-25. As noted, there are multiple potential pathways PFAS chemicals can take once leaving sources. For example, individual PFAS compounds can be released to the air from a manufacturing site, transported through the atmosphere, deposited to land or water elsewhere, and ultimately can accumulate in organisms. PFASs can also be discharged in effluent directly to a water body, or into a sewer system and transported to a wastewater treatment plant, which then releases the chemicals, whether in wastewater effluent, or via sludge disposal, e.g. through land application or incineration.

As noted above, once PFASs enter a water body, they can bioaccumulate into organisms from water and in some cases biomagnify up through food chains to become concentrated in upper trophic level biota. Studies conducted in both freshwater and marine ecosystems have shown PFAS accumulation into plankton and macrophytes (i.e. rooted plants at the base of the food web) as well as into fish that feed on these food items. However, the magnitude of this accumulation is PFAS-specific (e.g. chain length, head group, other structure aspects) and somewhat dependent on site-specific characteristics including whether it is a river or a lake/pond and on the species composition at the site of interest. An additional distinguishing feature is that unlike PCBs, dioxins and many other nonpolar organic pollutants, many PFASs tend to bind to proteins in organisms, rather than fatty tissues.[25]

An additional issue with PFASs is the potential for soil and groundwater contamination. As with other pollutants, understanding the movement of PFASs in soils and groundwater must consider multiple factors in the ground (e.g., type of soil, presence of roots, fractures, how readily water moves through the soil) and PFAS properties, including their ability to evaporate from soils or water, solubility (extent to which they can dissolve) in water, soil sorption (extent to which they attach to soil particles), biodegradation, and other factors.[26] Unlike some other organic pollutants such as PCBs and dioxins, where a major concern is biomagnification and resulting high fish tissue levels due to low water solubility and high lipid (fat) partitioning, many PFASs have a relatively higher tendency to stay in water rather than to adsorb or partition to soils, or build up in food webs. Thus, though they can build up to some extent in food webs (typically binding more to proteins), this buildup does not typically occur to the same extent as for example PCBs. This tendency to stay in water can lead to relatively higher levels of some PFASs in groundwater, including potential drinking water supplies, which can then pose risks to human health (see the Human Exposures and Effects of PFASs section on page 15). Findings of groundwater contamination on or around multiple military bases around the United States have affected drinking water supplies and led some communities to either add expensive drinking water treatment steps or avoid particular groundwater sources altogether.[27] This is important in many low-income communities that may be at risk of elevated exposures due to nearby military bases, industrial sites, or other contaminated sites (See Box 2). In cases of contamination in rural areas without municipal water supplies, options for residents may be limited to alternative water supplies (e.g. bottled water) and/or in-home treatment until groundwater contamination is addressed.

MEASURING PFAS IN THE GREAT LAKES ENVIRONMENT

Understanding the movement of PFASs in the environment entails measuring the chemicals in multiple environmental media, including air, water, soil, sediment, and biota such as fish and wildlife, in addition to having knowledge of their physical-chemical properties (such as their aqueous solubility, or extent to which they can dissolve in water). Measurement of PFASs in the environment has expanded significantly in the past decade. As with many organic pollutants, key steps in measuring PFASs include sampling a particular matrix (e.g. water or fish), extracting the sample (to obtain PFASs and related substances), cleaning up the extract (to isolate the PFASs of interest), and instrumental analysis.[28] Techniques have improved for analyzing for PFASs in all media (including monitoring in humans and wildlife) in the past decade.

However, because each step of the process is relatively involved, and the instrumental analysis needed for reliable quantification involves expensive equipment, such sampling and analysis is costly, and many entities (including drinking water treatment plants and wastewater treatment plants) may not have the capacity to do such analyses. While some states have established laboratories that are capable of analyzing PFASs, most do not have the capacity to handle the number of samples needed to have a robust monitoring program. Some drinking water or wastewater treatment plants may work with contract laboratories to carry out analyses of samples obtained at their plants, though there are a limited number of private labs with the capacity to analyze for PFASs.[29]

Increasing research into the presence of PFAS compounds in the Great Lakes environment is being carried out, with measurements having been done for multiple media (e.g. soil, sediment, water, fish), and findings from several studies are summarized in Table 2. (See Box 1 for a brief explanation of units commonly used in environmental measurements of PFASs and other pollutants.) In general, there has been less work done measuring PFASs in the region in surface water and air, likely due in part to sampling challenges. (Measurements in wildlife are discussed below.)

In reviewing information summarized in Table 2, several key findings include:

- Sediment studies show generally higher PFAS levels in Lakes Erie and Ontario, and some evidence of urban or other local sources (including elevated levels at a site in Lake Huron offshore of the former Wurtsmith Air Force Base).
- Sediment studies show some evidence of a relationship with use history (i.e., increasing concentrations of PFOS in the 1970s), though multiple factors complicate interpretation of the findings concerning trends over time.[30]
- Studies of PFASs in surface waters have typically found individual PFAS levels below approximately 30 ppt,[31] and PFOA typically higher than PFOS in Great Lakes waters.
- Studies of PFASs in fish tissue have often found PFOS at higher concentrations.[32]
- Groundwater studies near certain industrial or PFAS product use sites (e.g., former Wurtsmith Air Force Base) have documented extremely high concentrations, over thousands of times higher than more remote Great Lakes surface waters (also see Box 2).[33]
- There have been few determinations of PFASs in air, including in the Great Lakes.[34] A recent review on global measurements noted that in a number of studies involving air measurements, the fluorotelomer alcohol group of PFASs were among those most commonly detected, or at highest concentrations.[35]

BOX 1. A Note on Units

Concentrations of contaminants such as PFASs are expressed in units of mass of pollutant per mass or volume of medium. For example, a concentration of PFOS measured in soil of 5 ng/g indicates 5 nanograms of PFOS per one gram of soil. Because one nanogram is a billionth of a gram, this unit would be equivalent to 5 parts per billion (ppb). Also, metric system units from milli- and smaller are related by factors of 1,000. So for example, 1,000 ng/g = 1 ug/g (or 1,000 ppb = 1 ppm).

In water, concentrations are typically expressed as mass of pollutant per volume of water. For example a concentration of PFOS measured in water of 5 ng/L indicates 5 nanograms of PFOS per one liter of water. Because the density of water is 1.0 kg/L, 5 ng/L is equivalent to one part per trillion.

As a comparison, one part per trillion would be similar to a small drop of water in an Olympic-size swimming pool. It is important to note that though such concentrations may appear to be very low, there can still be ecological or human health concerns with exposures to certain chemicals in these (or even lower) concentration ranges.

Conversions between mass concentration units and parts units are as follows:

In soil, sediments, and fish:
- ug/g = microgram/gram = part per million (ppm)*
- ng/g = nanogram/gram = part per billion (ppb)
- pg/g = picogram/gram = part per trillion (ppt)

In water:
- mg/L = milligram/liter = part per million (ppm)
- ug/L = microgram/liter = part per billion (ppb)
- ng/L = nanogram/liter = part per trillion (ppt)

Concentrations in air for organic pollutants such as PFASs are typically not expressed in the parts-per system, though the conversion can be done.

**Note that in fish, concentrations are sometimes expressed as milligram/kilogram, which is also ppm.*

TABLE 2. PFAS Measurements in Great Lakes Region Soil, Sediment, Water, and Fish—Selected Studies[a]

GEOGRAPHIC AREA, PERIOD	MEDIA SAMPLED, PFAS COMPOUNDS	FINDINGS	REFERENCE
Lake Superior, 2002, 2005	Lake Superior water, tributaries, wastewater treatment plants for 23 PFASs	• PFOA dominant PFAS in Lake Superior water, ranging from 0.07—1.2 ppt • Tributaries major source (over 57% for both PFOA and PFOS) to Lake, with precipitation second most important source	Scott et al. 2010.[36]
Great Lakes, 2005—2010	Water, fish, including for newly identified PFASs	• Two cyclic PFASs (PFECHS and PFMeCHS)[b] identified in Great Lakes environmental media for first time • PFOS major aliphatic (straight-chain) PFAS found in fish (up to 96 ppb in Lake Erie lake trout) • PFOA dominant PFAS in surface waters (up to 5.5 ppt) • Log bioaccumulation factor[c] higher for PFOS (4.5) compared to PFOA (2.1)	De Silva et al. 2011[37]
Michigan, 2001	Surface waters, PFOS, PFOA[e]	• PFOS concentrations ranged from 0.9—29.3 ppt, PFOA concentrations from 1.2—35.9 ppt • Average concentrations for both were higher in southwest Michigan (though statistical analysis not indicated)	Taylor-Morgan et al. 2011[38]
Former Wurtsmith Air Force Base, MI	Groundwater, four PFASs	• PFOS concentrations ranged from 4 to 110 ppb; PFOA concentrations from < 3 to 105 ppb; PFHxS concentrations from 9 to 120 ppb; PFHxA concentrations from < 3 to 20 ppb	Moody et al. 2003[39]
Twin Cities Watershed (MN)	Soils near historic manufacturing/disposal sites, nine PFASs	• Average PFOS and PFOA in soils higher than the soil screening level (3 ppb) developed in the study • Groundwater concentrations as high as 20,000 ppt, decreasing away from sources • Relatively little change from 2009-2013 indicates potential for ongoing groundwater contamination for years	Xiao et al. 2015[40]
Lake Superior, northern Lake Michigan, Lake Huron, 2011, 2012	Sediments, 22 PFASs	• Mean total PFAS concentrations of surface sediments ranged from 1.5—4.6 ppb • Lower PFAS concentrations than other lakes (next study), but indication of local sources in some cases • Some apparent relationship to PFAS use history, but challenges in assessing temporal trends	Codling et al. 2018a[41]
Lake Erie, Lake St. Clair, Lake Ontario, 2013, 2014	Sediments, 22 PFASs	• Mean total PFAS concentrations of surface sediments ranged from 15.6—19 ppb • Higher total PFAS concentrations near urban areas • PFBA and PFHxA[d] commonly detected, indicating shift in use patterns • Challenges in assessing temporal trends	Codling et al. 2018b[42]

a: See Box 1 for an explanation of units. Note that values provided in findings column are expressed in parts-per units, though original publications typcally provided values in standard mass concentration units.

b: PFECHS is perfluoro-4-ethylcyclohexane sulfonate; PFMeCHS is perfluoro-4-methylcyclohexane sulfonate.

c: Bioaccumulation factor is the ratio of the concentration of a contaminant in an organism to the concentration in surrounding environment, considering all exposure pathways.

d: PFBA is perfluorobutanoic acid; PFHxA is perfluorohexanoic acid.

e: State coordinated monitoring carried out in 2001.

Concerning chemical monitoring in the Great Lakes generally, systematic monitoring is carried out by the U.S. and Canadian governments (coordinated by the U.S. EPA and Environment and Climate Change Canada) as called for under the Great Lakes Water Quality Agreement (GLWQA) (see international discussion on p. 33). Annex 10 of the GLWQA calls for the development of ecosystem indicators, and through the Agreement, U.S. EPA and Environment and Climate Change Canada issue State of the Great Lakes reports currently on a three-year cycle, with the reports "describing basin-wide environmental trends and lake-specific conditions using environmental indicators."[43] The monitoring effort has expanded through the years to include chemicals of emerging concern, though through the most recent report, PFAS levels were not reported. However, the report also indicated the agencies were considering including PFASs in future assessments, and note that some states and Ontario have made PFAS monitoring and surveillance a priority.[44] Additional PFAS monitoring has also been carried out by Canadian agencies, though it is not a focus of this report.[45]

A recent effort by Environmental Working Group and Northeastern University's Social Science Environmental Health Research Institute (SSEHRI) to compile and map publicly available information on levels of PFAS compounds in drinking water supplies and water on or near military bases around the U.S. reported 610 sites in 43 states with one or more detected PFAS compounds present, as of March 2019.[46] Michigan (with 192 sites documented) was the state with the largest number of PFAS-contaminated sites. However, as noted by the map developers, in addition to indicating extensive contami-

BOX 2. Military Use of PFAS-Containing Firefighting Foam

Beginning in the 1970s, the U.S. Department of Defense began using aqueous film forming foams (AFFFs or "fluorinated firefighting foam") in firefighting applications, in particular for petroleum fires. These foams contain surfactants (including based on PFASs) combined with organic solvents and water, that act to smother the hydrocarbon fire, which can be challenging to extinguish otherwise.[51] The formulations often contained PFOS, and in some cases, PFOA. The Federal Aviation Administration ultimately required use of these fluorinated firefighting foams at all airports around the country, through adopting specifications used by the military.[52] The widespread use of these foams at military bases led to significant contamination at many bases, including via use at firefighting training areas, hangars, fire suppression systems, and crash sites. Although a voluntary phaseout of PFOS-containing product manufacturing began in 2000, it is possible uses have continued to the present, given significant stockpiles of the foams. Due to concerns with PFOS releases, the Department of Defense issued a human health and environmental risk alert in 2011, which included guidelines for addressing potential releases of PFOS.[53] It should be noted that PFOS substitutes are typically fluorinated compounds which can have their own environmental concerns.

As of December 2016, the Department of Defense had identified 393 active and former military installations with known or suspected histories of PFOS and/or PFOA releases. Over 60 of the facilities—mostly Army and Air Force—are located in the Great Lakes states.[54] One such facility is the former Wurtsmith Air Force Base, near Oscoda, Mich., the first military base at which PFAS contamination was reported. As recently as 2011, the facility was the only known source of PFAS contamination in Michigan,[55] though in the meantime, the state has embarked on an extensive monitoring program statewide, as noted above. Earlier monitoring at Wurtsmith reported elevated levels of four PFASs in groundwater, including concentrations as high as 120 micrograms/liter (or parts per billion) five years after the base was closed (see Table 2 on the previous page).[56] Note these values are up to 10,000 times higher than typical surface water PFAS concentrations in more remote areas, and over 1,000 times higher than EPA's drinking water health advisory, which itself may not be protective, as discussed below. Subsequent monitoring by the Michigan Department of Environmental Quality confirmed elevated groundwater PFAS concentrations in multiple locations on or near the base.[57] Elevated PFAS levels were also found in fish, including in an adjacent marsh and the Au Sable River. Concentrations as high as 9.6 micrograms/gram (or parts per million) were measured, leading to issuances of fish consumption advisories for the area.[58] Work since then has also documented the presence of PFASs in deer in the area, which led to the issuance of a "Do Not Eat" advisory for venison in the area (see further discussion in the Human Exposures and Effects of PFASs section on page 15).

nation, the high number for Michigan may also reflect more extensive monitoring carried out by the state in the recent past.

Indeed in 2018, the Michigan Department of Environment, Great Lakes, and Energy (EGLE, formerly the Department of Environmental Quality) began statewide sampling of public water supplies, and work is continuing in 2019 targeting sites found to have more than 10 ppt PFOA/PFOS total.[47] The state is currently investigating 64 PFAS contaminated sites.[48] The state has also focused extensive efforts in particular watersheds, including the Huron River in southeastern Michigan, following findings of elevated levels in drinking water by the city of Ann Arbor in 2014. Subsequent work in the watershed identified elevated PFAS levels in wastewater treatment plant influents and effluents, drinking water, and fish, which has led to both control actions and issuance of fish consumption advisories (see further discussion in the Human Exposures and Effects of PFASs section on page 15).[49]

Given the lack of systematic, representative monitoring done in the Great Lakes or around the United States, the extent of PFAS contamination across the Great Lakes states and nationally is likely underestimated. Given the plethora of PFAS uses in products and thousands of sites of potential significant use (e.g. firefighting foam), it is likely more systematic monitoring will reveal numerous sites around the region and country with PFAS contamination. A recent study captured the challenges in assessing the full extent of PFAS contamination in the environment. In a systematic analysis of manufactured chemicals, products, and groundwater contamination at 15 military sites, the researchers discovered 40 *classes* (each with potentially multiple individual compounds) of PFASs produced via two different manufacturing processes, suggesting yet additional presence of persistent PFASs in the environment.[50]

Ecological Exposures and Effects of PFASs

OVERVIEW

As with other toxic chemicals, understanding implications of PFASs for organisms in the environment entails assessing exposures (i.e., including the amount of chemical taken up by an organism, the exposure route, etc.) as well as effects. As with other environmental media (e.g., water, soil), assessing exposure entails obtaining samples via some type of standard protocol, processing, and analyzing the sample. In the case of fish, when not focusing on human exposures to fish contaminants, exposures are often assessed based on the whole fish sample. In the case of wildlife, sampling is more commonly done for individual organs or other tissues (e.g. liver, blood, eggs, muscle, or fur). Assessing effects of toxic chemicals is more involved, and typically entails either lab toxicological studies on model organisms (e.g., zebrafish or bobwhite quail) or field observational studies, in which measurements of tissue concentrations as well as potential effects, such as measures related to development, growth, or reproductive success, are obtained, and statistical/modeling analysis is carried out. The field of forensic ecotoxicology has developed in a manner that often integrates both components, where insights from controlled studies (e.g., in laboratory) and field observations are used to establish cause-effects linkages involving toxic chemicals and wildlife.[59]

In the case of PFASs, there has been increasing research over the past two decades on both ecological exposures and effects, but with greater emphasis on the former. Physical-chemical properties of PFASs and their environmental cycling, including the partitioning between air, water, soil and sediment compartments, are important in affecting potential exposures of organisms. As noted previously, PFASs are typically very persistent in the environment, but have different tendencies to bioaccumulate, depending on chemical structure and organism of concern. As with other organic contaminants such as PCBs, some PFAS chemicals can both be taken up at the base of food webs (e.g. free-floating algae, or phytoplankton), and increase in concentrations (biomagnify) going up the food web, to forage fish, predator fish, and fish-eating wildlife. But for many PFAS chemicals, fish uptake occurs mainly from the water, and less so via diet (i.e., what would lead to biomagnification).[60] In addition, unlike more nonpolar pollutants such as PCBs that tend to associate with fatty tissue in organisms, most PFASs tend to associate with protein-rich regions in an organism (e.g. liver, blood plasma).[61]

Since the early 2000s, an increasing amount of research has documented fish and wildlife exposures to PFASs, and in some cases effects of PFASs. In both cases, much of the emphasis has been on the two commonly used chemicals, PFOS and PFOA. Research using a number of organism groups, including aquatic plants, phytoplankton, zooplankton (free-floating microscopic animals), amphibians, and fish, and to a lesser extent birds and mammals, has accelerated in the past 10-15 years.[62] In birds, controlled studies have examined both acute (shorter term) and chronic (longer term) toxicity, and dosing of PFASs is typically based on either feeding adults or juvenile birds or egg injection in studies that evaluate molecular and biochemical mechanisms of toxicity.[63] In many studies up to the early 2000s conducted with fish and wildlife species, the focus was on endpoints such as survival, growth, and early life stage viability.[64] However, over the last 10 years additional effort has been put into understanding the mechanisms of toxicity for different PFASs that include immunotoxic, neurotoxic and developmental mechanisms in both fish and wildlife.[65]

For example, laboratory studies on PFASs in fish have shown impacts on gene expression involving several systems (including estrogen production) in zebrafish,[66] and other studies (in particular using PFOS) have found impacts including reduced number of viable eggs, reduced body size, and altered sex ratio.[67] Laboratory studies on birds have shown impacts such as reduced hatching success associated with elevated PFAS levels, though challenges in carrying out and interpreting data from these studies is recognized (see discussion below). There have been relatively few studies on PFAS uptake and potential effects in amphibians and reptiles[68]—(see further discussion in next session).

One of the first papers published documenting levels of PFASs in fish and wildlife in the wild reported on measurements for four PFASs from organisms at 17 sampling sites around the world.[69] Only PFOS data were generally above quantification limits, but the data showed the presence of PFOS in diverse fish and wildlife samples, ranging from more industrialized areas (including bald eagles, other birds, and fish in the Great Lakes) to remote areas (albatross in the North Pacific and seals in the Canadian Arctic). In general, PFOS concentrations were higher in the more developed/industrialized areas, though the presence in remote areas indicated the potential for PFOS to be transported long distances via the atmosphere or water from original sources.[70]

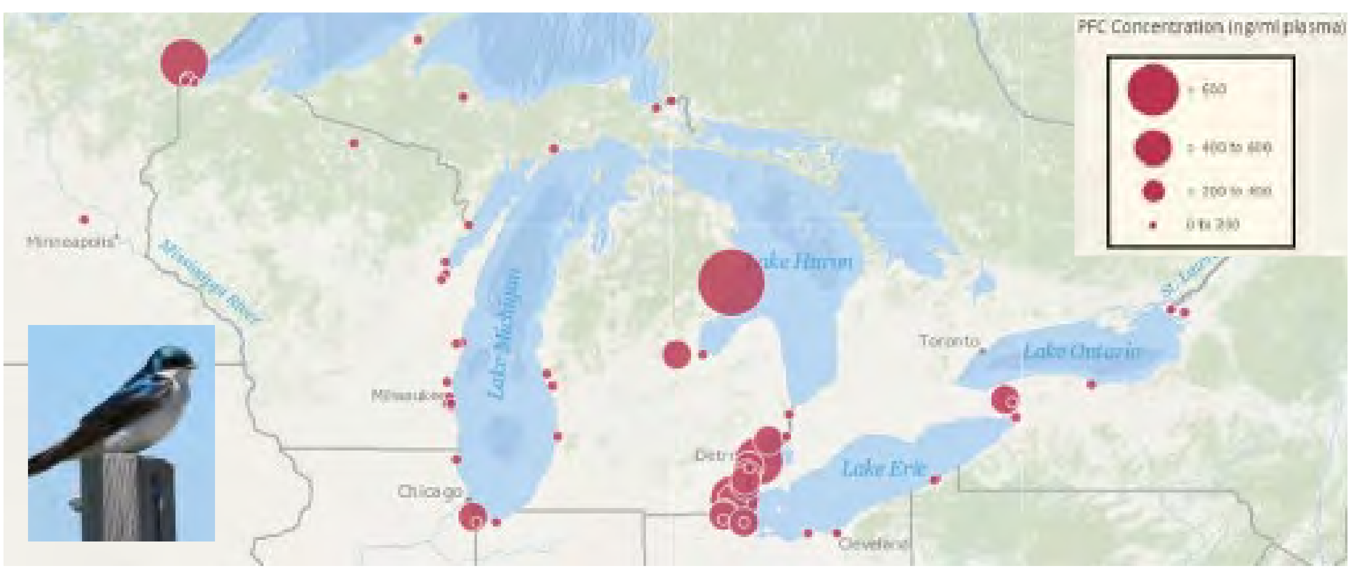
PFAS ECOLOGICAL EXPOSURES AND EFFECTS STUDIES IN THE GREAT LAKES REGION

A handful of studies in the past decade have documented exposure (and in some cases effects) to PFASs in fish and wildlife in the Great Lakes region. A study published in 2005 documented the presence of several PFASs in a number of aquatic species, including Chinook salmon, round gobies, snapping turtles, green frogs, mink, and bald eagles, with PFOS typically the dominant PFAS measured, and indicating both bioaccumulation and biomagnification (increasing concentrating at higher levels in the food web).[71] More recent studies on ecological exposures and effects studies in the Great Lakes region are summarized in Table 3. (Note further discussion of PFASs in fish filets and relevance to human exposures are provided in the following section.)

As summarized in Table 3, most field studies to date of PFASs in Great Lakes wildlife have focused on birds. One common feature of most of the studies summarized in Table 3 was the finding of higher concentrations of the PFSA group of chemicals compared to the PFCA group, as well as PFOS being found at highest concentrations of any PFAS, which likely results from a combination of historic use patterns, persistence in the environment, and tendency for bioaccumulation by organisms.

Tree swallows are one species that has been heavily studied in the region. As shown in the map in Figure 2 summarizing tree swallow blood plasma PFAS data,[81] levels varied quite significantly in the region, with higher contamination levels in several areas of the Great Lakes, including Wild Rice Lake near Duluth, Minn.; Oscoda, Mich. (and the former Wurtsmith Air Force Base); and the Huron-Erie Corridor.

FIGURE 2. Map showing total PFAS levels in tree swallow blood plasma in Great Lakes region, from monitoring in 2011-2015[82]



A typical tree swallow (Tachycineta bicolor) studied by the scientists. Photo credit: Thomas Custer.

TABLE 3. Summary of Recent Field Studies on PFASs in Wildlife in Great Lakes Region

GEOGRAPHIC AREA	ORGANISM(S) SAMPLED, APPROACH, PFAS COMPOUNDS	FINDINGS	REFERENCE
Atlantic to Pacific Canada, including two Great Lakes sites	Eggs from four species of gulls, for 21 PFASs, in marine and freshwater environments	• PFOS was most prevalent PFSA[a], • Highest PFSA concentrations were in urban areas of Great Lakes and St. Lawrence River (up to 486 ng/g, or ppb) • Dietary sources of the PFSA were colony-specific, and typically both terrestrial and aquatic prey for freshwater birds	Gebbink et al. 2011[72]
Twin Cities area, Minnesota	Tree swallow tissues, for 13 PFASs	• PFOS was dominant compound at both more contaminated Lake Johanna and reference lake • PFOS concentrations elevated in all tissues in swallows from Lake Johanna compared to reference lake • Higher PFOS concentrations in eggs was associated with lower hatching success	Custer et al. 2012[73]
Minnesota and Wisconsin	Tree swallow eggs at eight sites for 10 PFASs	• Eight PFASs detected in over 50 percent of samples, and PFOS typically at highest concentrations • Highest PFAS and PFOS concentrations seen at site near historic PFAS disposal site • Higher PFOS concentrations in eggs was associated with lower hatching success • Reproductive effects calculated to occur at factor of 10-100 times lower concentrations than found in laboratory studies	Custer et al. 2014[74]
Minnesota	Great blue heron eggs, for 11 PFASs	• Total PFAS concentrations 60 percent lower in 2010-11 compared to 1993, though higher for subgroup PFCA[b] • Highest total PFAS concentration in one egg (2,506 ng/g) among highest reported to date in bird eggs • High concentrations at levels associated with physiological effects (e.g. brain asymmetry, immune alterations) in studies of lab animals	Custer et al. 2013[75]
Great Lakes	Herring gull eggs, at 19 Canadian and U.S. sites, for 18 PFASs and two precursor compounds	• Total PFSA concentrations ranged up to 740 ng/g, with PFOS the dominant compound • Total PFSA concentrations generally increased towards southeast (eastern Lake Erie and Lake Ontario colonies) • PFOS concentrations in some samples were at levels associated with effects from lab studies	Letcher et al. 2015[76]
St. Mary's River and Saginaw Bay, Michigan	Caspian tern and herring gull eggs, for 87 contaminants of emerging concern	• Total PFSA concentrations were the highest amongst the chemicals groups, followed by PFCA and then other groups • Mean PFSA and PFCA concentrations were up to 10 times higher in tern compared to gull eggs • Elevated PFOS levels were in the range where observable effects on hatchability are seen in laboratory studies	Su et al. 2017[77]
27 Great Lakes Areas of Concern (AOCs)	Tree swallow nestling plasma in 27 AOCs and 9 non-AOC sites, for total PFAS and other contaminants, 2010-14	• PFOS concentrations highest at River Raisin (Mich.) and Detroit River sites, but below toxicity threshold • PFOS concentrations at two non-AOC sites (Oscoda, Mich., and Wild Rice Lake, Minn.) highest among all sites • Other field evidence indicates risk of PFAS-related reproductive impairments at the higher contaminated sites	Custer et al. 2017[78]
Oscoda Township, Michigan	Tree swallow eggs (and other tissues), for 13 PFASs	• Site has some of highest reported PFAS levels in birds in U.S. • PFOS was detected in all samples and all tissues • No change in total PFAS egg concentrations over time (2014-2017) • There were no reproductive or physiological response effects attributable to PFAS exposures, comparing Oscoda to reference sites.	Custer et al. 2019[79]
Upper Midwest (Michigan, Wisconsin)	Bald eagle nestling blood plasma, for 19 organic contaminants	• In general, PFAS compounds were found at higher concentrations than other compound groups (phthalates, flame retardants, and others) • PFOS had the highest ratios of concentrations measured compared to concentrations expected to cause biological effects amongst all contaminants[c]	Elliott et al. 2019[80]

a: PFSAs is perfluoroalkyl sulfonic acids.

b: PFCAs is perfluoroalkyl carboxylic acids.

c: Biological effects information derived from ToxCast database, which utilizes a screening level approach to estimate effects of particular contaminants on organisms (with an emphasis on mammals) (see reference 80).

Another common feature of most studies summarized is an emphasis on measurements of PFAS exposure in birds. In some cases researchers included comparison to levels likely to cause effects, based on laboratory or modeling studies. The tree swallow studies are among the few anywhere to both measure PFAS compounds and assess potential effects in the field. The earlier study documented both higher PFOS levels at Lake Johanna, Minn. (previously known to have higher contaminant levels) compared to a reference lake, and reduced hatching success associated with higher PFOS levels in the eggs.[83] Similar findings of reduced hatching success were reported for tree swallow studies at a larger number of sites in Minnesota and Wisconsin.[84]

The recently published study on tree swallows in Oscoda Township, Mich., was able to focus on impacts associated with PFASs, given other contaminants are present at lower levels. Though the study reported among the highest levels of PFASs found in birds anywhere in the United States, no reproductive or physiological impacts (e.g., patterns of a detoxifying enzyme, or changes in thyroid hormones) were observed, when comparing Oscoda to reference sites, including other Great Lakes sites with lower contamination. The authors noted that possible explanations for observing PFAS-related effects in tree swallows in the upper Mississippi River sites (Table 3) is their interaction with other measured organic contaminants and potentially the presence of unmeasured contaminants at those sites.[85]

Though not a focus of this report, studies of PFAS exposures and effects in wildlife in other locations around the world have been carried out, including a study of cormorant eggs and harbor seal blood serum in San Francisco Bay, which among other findings identified a precursor PFAS chemical present at elevated concentrations;[86] a study of insectivorous bird species in Belgium that reported a general decrease in PFAS concentrations with distance from a fluoro-chemical manufacturing plant;[87] and a study on ringed seals in Norwegian fjords, showing mixed results concerning PFAS concentration trends from 1990-2010.[88] More studies exploring these types of spatial and temporal trends of PFAS contamination in wildlife are needed in the Great Lakes region.

Two organism groups that have been studied very little concerning PFASs (both lab toxicity studies and field studies) are amphibians and reptiles.[89] One recent study examined PFAS uptake in controlled outdoor conditions for larval northern leopard frogs, American toad, and eastern tiger salamander, and found uptake was rapid, reaching steady state (where concentrations were not changing with time) within 144 hours for each species/chemical. Bioaccumulation was 1-2 orders of magnitude (factor of 10-100) higher for PFOS compared to PFOA, and bioconcentration factors (or ratio of chemical in the organism to chemical in surrounding water) varied with chemical concentration and species, as has been found in other studies, including for fish. Given the physical-chemical properties of PFASs, the researchers noted PFASs may be present in many wetlands, with potential implications for exposures (and effects) in amphibians, as well as their predators.[90] Though not relevant to the Great Lakes, recent research has been published on PFAS levels in reptiles in the southeastern U.S.[91]

SUMMARY OF PFAS ECOLOGICAL EXPOSURES AND EFFECTS STUDIES IN THE GREAT LAKES REGION

Based on this brief review of PFAS contamination and Great Lakes ecosystems, several findings include the following:

- There have been an increasing number of studies on PFASs and wildlife in the Great Lakes, with the majority involving measurement of PFAS exposure in bird species.
- PFOS is generally the PFAS compound at highest concentrations found in Great Lakes region birds.
- Studies on tree swallows in the region have explored both PFAS exposure and effects, and have observed an association between reduced hatching success and elevated PFAS exposures.
- For other birds, higher concentrations found in some studies in the region are in the range of potential biological effects based on laboratory studies.
- PFASs were the most prevalent organic contaminant group found in bald eagle nestlings in the Upper Great Lakes in a recent study, and there is concern about potential effects, based on screening levels.

Given the varying factors (including other chemicals) that can affect organisms in the environment, multiple considerations are often used to link PFAS exposures with specific effects in wildlife or other organisms. As for other toxic chemicals, thresholds of concern for PFASs (such as lowest observed adverse effect level, or LOAEL) are often obtained via controlled laboratory studies, where dose-response studies are carried out with a model organism, and specific effects are measured, allowing for determination of the level at which effects start to occur (the LOAEL).[92] Then those levels can be compared to levels for the chemicals of interest found in the organism in the wild. These data can also be used to conduct screening level ecological risk assessments that use site-specific data and laboratory toxicity data to predict potential impacts to avian populations. For example, a study that modelled the exposure of four bird species to seven PFASs from sediment and water collected from military bases in the United States concluded that there was a potential for adverse effects for several species directly or indirectly exposed to PFASs via benthic macroinvertebrates, including spotted sandpiper and great blue heron.[93]

Another approach is to design field studies to determine exposures across a gradient (i.e., low PFAS concentration to high), and determine any changes in effects, as was done regarding tree swallows as noted above, and was done for insectivorous birds near a fluoro-chemical plant in Belgium, as noted previously.[94]

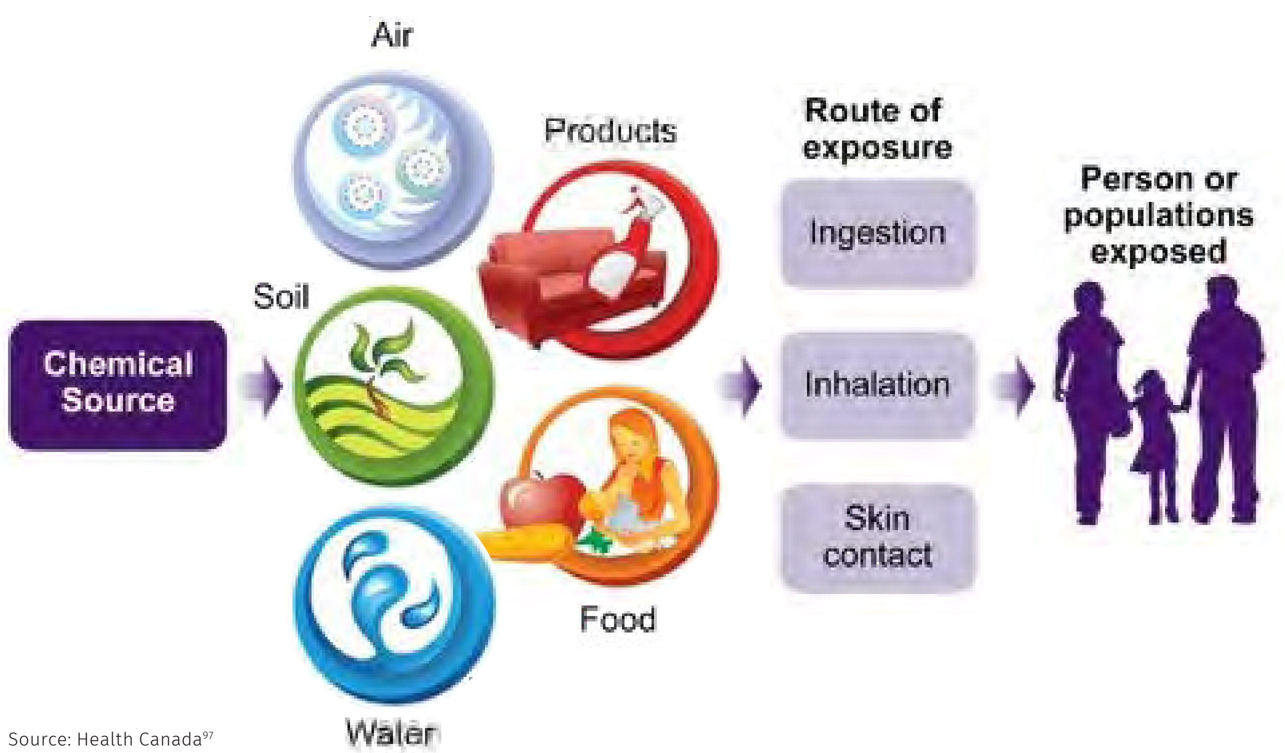
As noted by researchers, there are challenges in relating thresholds identified in laboratory studies to the field, including factors such as differences in the lab environment compared to the wild (including not accounting for all factors that may affect hatching success), differences in exposure (e.g., egg injection of contaminants in the lab), potential differences in species sensitivities to pollutants such as PFASs, and the presence of other contaminant groups.[95] In addition, any studies of potential impacts of chemicals such as PFASs on wildlife must account for other factors that includes intrinsic aspects such as reproductive strategies, sexual differentiation, and hormone levels, in addition to behavioral patterns such as seasonal changes in migration, dietary composition, competition with other species and predation.[96] Although there is reason for concern about wildlife susceptibility to PFASs in the region based on research to date, further lab and field studies are needed to explore potential exposures and impacts of the various PFAS chemicals to a wider variety of species in the Great Lakes.

Human Exposures and Effects of PFASs

OVERVIEW OF HUMAN EXPOSURES TO PFASS

Human exposure to PFASs must account for the full lifecycle of PFASs, from chemical and product manufacturing, to product use, waste disposal, environmental cycling, which then has implications for the various routes of entry into people. A schematic showing these processes is provided in Figure 3. The multiple sources, complex lifecycle, and varying physical-chemical properties of PFASs means the chemicals can be present in many environmental media (as noted in previous sections), and consequently that human exposures can also occur through multiple routes, as briefly summarized below.

FIGURE 3. Pathways from chemical sources to human exposures, which is applicable to PFASs



Source: Health Canada[97]

As indicated in Figure 3, the potential routes of chemical exposure are ingestion (including both food and drinking water intake), inhalation (which can also occur in occupational settings), and skin contact. It is thought that skin exposure is relatively low for PFASs.[98] Because PFASs have had significant historic use in consumer products (as summarized in Table 1), there is potential for direct human exposure (e.g., ingestion from cookware, food packaging material, or inhalation of dust from clothing), as those products breakdown with time. An additional complicating factor concerning quantifying PFAS exposures is the potential for metabolism of compounds in the body to other compounds that may still pose health risks. In addition, though there has been significant research on exposures to PFOS and PFOA, it is important to consider exposure to other PFAS substances that have come into use since the phase-out of PFOS and PFOA.[99]

Drinking water is a potential source of PFAS exposure for many individuals, including those living in areas with contaminated sites, such as manufacturing facilities or military bases. PFAS drinking water contamination was first identified near a manufacturing facility in West Virginia in 1999, and as previously noted, was identified in 2010 at the former Wurtsmith Air Force Base in Michigan in private drinking water wells at parts per billion levels.[100]

BOX 3. Fish, PFASs, and Exposures and Effects in the Great Lakes Region

Although fish tissue monitoring for chemicals such as mercury and PCBs has been occurring in the Great Lakes for decades, monitoring for PFASs started in earnest just in the past decade. As part of U.S. EPA's National Rivers and Streams Assessment and the Great Lakes Human Health Fish Tissue Study of the 2010 National Coastal Condition Assessment, fish were sampled and analyzed from 157 Great Lakes nearshore sites (as well as 164 urban river sites from around the U.S.). As has often been the case in wildlife studies, PFOS was the most common PFAS measured in fish, followed by three PFCA compounds. Maximum PFOS concentrations were 80 ng/g in the Great Lakes samples, vs. 120 ng/g among the urban river samples, though median PFOS concentrations were higher in Great Lakes samples (15.2 ng/g) vs. urban river samples (10.7 ng/g).[107]

Another program has been underway through the Great Lakes Restoration Initiative (GLRI), the main federally funded program supporting restoration efforts in the region. Through GLRI funds, the Biomonitoring of Great Lakes Populations program has been underway since 2010, under the Agency for Toxic Substances and Disease Registry (ATSDR). The first phase of the program involved cross-sectional studies in Michigan, Minnesota, and New York of susceptible populations (e.g. urban anglers eating locally caught fish). Though covering multiple contaminants, sampling for some PFASs was carried out in selected populations (see further discussion in the Potential Environmental Equity and Justice Implications of PFAS Contamination section on page 18).

In addition, a separate study of male anglers in Wisconsin explored the relationship between tissue levels of multiple contaminants (including blood for PFASs) and fish consumption. The researchers found that for all of the PFASs studied except PFHxS, consumption of Great Lakes fish (including from Areas of Concern, so-called toxic hot-spots) was associated with higher PFAS levels. The authors noted one limitation in the study in that there can be other sources of PFASs (e.g. drinking water, direct exposure from products) that they did not consider.[108]

In a recent study on fish contaminants (including PFOS) and advisories in the Canadian portion of the Great Lakes, researchers found that based on hazard indices they derived, PFOS posed fewer risks to fish consumers in the province compared to other contaminants (in particular mercury, PCBs, and total dioxin-like compounds), which would remain responsible for most advisories.[109] However, the researchers did find that assuming additive effects of contaminants, the advisories in general may not be protective.[110] It is also important to note that in locations closer to PFAS-contaminated sites, presumably PFOS and other related compounds would become more significant in posing health risks (and affecting advisory development), based on the methodology used—see further discussion in the Approaches for Reducing Human Exposures to PFASs section on page 19.

In general more monitoring is needed for PFASs in the region, including fish tissue and human biomonitoring, and programs such as the Great Lakes Restoration Initiative, through the Toxic Substances and Areas of Concern focus area, should ramp up such efforts, potentially through interagency agreements with states.

A study using data from U.S. EPA's Unregulated Contaminant Monitoring Rule program under the Safe Drinking Water Act found public water systems serving over six million people in total exceeded the agency's 2016 health advisory levels for PFOS and PFOA (see further discussion below).[101] The same study found 13 states accounted for three-quarters of detections, including Illinois, Minnesota, New York, Ohio, and Pennsylvania in the Great Lakes region, and nationwide, each additional military site within a given watershed was associated with 35 percent higher PFOS concentrations.[102] A recent study noted that higher PFAS levels in water or higher than average drinking water consumption rates can lead to blood serum PFOA concentrations well above even the 95th percentile levels in the population (i.e., where 95% of individuals have lower levels).[103]

Food, and in particular freshwater fish and seafood, can be an important source of PFAS exposures. In Europe, where more such studies have been carried out, research has shown associations between blood serum PFAS levels and fish consumption, though variability has been seen.[104] A study using data from the National Health and Nutrition Examination Survey (NHANES) in the United States found higher blood serum PFAS levels associated with high-frequency fish consumers, with the strongest association with shellfish.[105] In addition, the researchers reported the NHANES data revealed a general decline in PFOS and PFOA blood serum concentrations from 2007-08 to the more recent biennial sampling periods.[106] Efforts to monitor human exposure to PFASs via fish consumption in the Great Lakes Region are summarized in Box 3.

An additional potential source of human exposure can be through other food items, which can be contaminated in multiple ways. One such pathway would involve wastewater treatment plants: In addition to discharging PFASs in effluent water, PFASs can be present in sewage sludge. Much of the sludge generated at wastewater treatment plants in the United States is processed on-site (e.g., via anaerobic digestion and drying), and the resulting "biosolids" can be applied to agricultural fields. This agricultural application of biosolids could potentially result in plant uptake of PFASs, and ultimately lead to human exposures via crops, or animal products.[111] A recent limited assessment by the U.S. Food and Drug Administration reported quantifiable levels of at least one PFAS in 14 of 91 food items sampled, though no assessment of potential PFAS sources was carried out.[112]

Regarding assessment of all human exposure routes to PFASs, Sunderland et al. (2019) noted that most studies to date have examined exposures to PFOS and PFOA, and in most cases, diet was the dominant pathway, typically followed by tap water, and in several cases dust exposure.[113] One study found relatively greater importance in PFAS exposures for tap water, for both perfluorobutanoic acid (PFBA) and perfluoro-n-hexanoic acid (PFHxA).[114] There are challenges in fully assessing all exposures to PFASs, including lack of comprehensive data for all potential media (air, water, food, etc.), possibly limited information on contact frequency, and uncertainties in toxicokinetic data (related to the body's processing of ingested chemicals). Alternative approaches are being pursued as well, such as examining the concentration ratios of different PFASs (including in the body and the environment) to infer potential sources.[115]

The amounts of PFASs stored in humans (or body burdens) have been changing over the past two decades in the United States, with a general decline in PFOS and PFOA documented in different populations, associated with the phase-out and stewardship programs for those chemicals. However, measurements of other PFASs, in particular compounds developed and used more extensively following the reduction in PFOS and PFOA, as well as precursor chemicals, have not been assessed to nearly the same extent, so questions remain on human exposure amounts (and trends) to all PFASs, including some of the newer compounds which can take longer to be cleared by the body.[116] One approach researchers have taken to assess for the presence of PFASs is analyzing for extractable organic fluorine (including in human biomonitoring), which can indicate the potential presence of other PFASs, even if the identities of individual compounds is not clear.[117]

EFFECTS OF PFASS IN HUMAN POPULATIONS

Two broad approaches to assess potential human health concerns for any toxic chemical are laboratory studies with model organisms (e.g. mice or rats) and human epidemiological studies, in which assessments of exposures to the chemical of concern are coupled with information on effects thought to be related to the exposures. Many of the earlier health exposure and effects studies of PFASs were carried out by 3M, the major manufacturer of many of the chemicals through the 1990s, though in the meantime, a number of laboratory and epidemiological studies have been carried out. Earlier 3M studies identified increased exposures of workers to PFASs compared to the general population. An earlier rhesus monkey study was abandoned after all monkeys died, and a later study with lower doses showed impacts on cholesterol levels, liver weight, and the immune system.[118]

While lab animal studies have been carried out exploring potential effects of PFASs, because of differences in a biochemical response to PFASs in lab animals compared to humans, findings from lab studies may not always be transferable to understanding human health risks from PFASs. Concerning epidemiological studies, one of the most comprehensive concerning a PFAS-contaminated site is the C8 Health Project involving people living near a fluoro-chemical plant in West Virginia, in which probable associations were found between PFOA and six illnesses, including high cholesterol, thyroid disease, and pregnancy-induced hypertension. Other research has shown potential increased sensitivity of children to PFASs, with increasing exposures associated with dyslipidemia (impaired ability to break down fats), and impacts to immune system, kidney function, and age at menarche (first menstrual period in female adolescents).[119]

In general, potential health effects from PFASs are seen across a number of endpoints, including the following:

- **Cancers:** Increased risk of testicular and kidney cancers with higher PFAS exposures, found in the C8 Health Project. Another research project examining data for the general population has not shown an association between PFOS and PFOA and several cancers. However, the International Agency for Research on Cancer has classified PFOA as possibly carcinogenic, and U.S. EPA determined there is "suggestive evidence" of carcinogenicity for both PFOA and PFOS.[120]
- **Immune system impacts:** Associations between PFASs and immune system effects have been seen in a number of studies, with impacts ranging from the molecular level (such as antibody production) to organ or system level (e.g. infections and asthma exacerbation).
- **Metabolic effects:** Multiple studies have shown associations between PFASs and elevated total cholesterol and low-density lipoprotein (or "bad") cholesterol. Evidence for other relationships, including diabetes, insulin resistance, overweight and obesity, and other metabolic diseases is less consistent.[121]

Other effects associated with PFAS exposures, including neurodevelopmental (e.g., attention deficit/hyperactivity disorder), cardiovascular disease, and endocrine disruption have not been as consistently documented in epidemiological studies,[122] indicating the need for further research. For example, the potential for certain PFASs to act on the endocrine system has been indicated in a recent study finding an association between perfluorononanoic acid (but not several other PFASs) and the thyroid hormone T4 in First Nation children in Quebec.[123]

POTENTIAL ENVIRONMENTAL EQUITY AND JUSTICE IMPLICATIONS OF PFAS CONTAMINATION

Researchers have frequently documented elevated contaminant exposures in populations or communities with fewer resources to address the problems, including communities of color and low-income communities.[124] Concerning PFASs and disproportionate exposures, there has been limited work concerning communities in the Great Lakes region. At the national level in the United States, in the recent analysis of NHANES data reported above, the association between PFAS exposures and fish consumption was generally stronger for higher income individuals, [125] and a meta-analysis of five studies (three in the U.S. and one each in Belgium and Norway) reported higher internal exposures to four PFASs associated with higher income individuals,[126] a pattern also seen in one of the studies included, covering the NHANES 2003-06 sampling round in the United States.[127] That same study found no differences in median blood contaminant levels for three PFASs between whites and non-Hispanic African Americans, and slightly higher levels for PFOA in whites.[128]

Given their aims, broad scope, and limited spatial resolution, national surveys would not typically be able to identify local communities at risk for higher exposures to PFASs or other toxic chemicals due to nearby military bases, manufacturing sites, or hazardous waste sites. In the case of the latter, earlier research showed that while people of color made up one-quarter of the U.S. population in 1990, they made up 40 percent of the population living within one mile of a hazardous waste treatment, storage, and disposal facility.[129] Other more vulnerable communities can also be affected by nearby manufacturing sites, including for example, the predominantly white, working-class community of Little Hocking, Ohio, which experienced elevated PFOA (or "C8") exposures and effects associated with an upstream manufacturing facility.[130] It is also important to consider other PFAS exposure routes. For example, a study involving 178 middle-aged women in the Child Health and Development Studies program found that African-American women had lower levels of PFOA and PFHxS than Non-Hispanic white women, though for African-American women, higher levels of four PFASs were associated with frequent consumption of food in coated cardboard containers. Other factors (including stain-resistant carpet or furniture and a PFAS-contaminated water supply) were also associated with increased levels of several PFASs.[131]

One of the few studies that has examined disproportionate PFAS exposures in a Great Lakes community is the Study of Women's Health Across the Nation, a study addressing middle age women which has focused on several geographic areas, including southeast Michigan. A recent publication from that project reported that for 1999-2000 exposure data, African-American women in southeast Michigan had higher levels of PFOS and another PFAS compound compared to white women, and in considering data from all areas, factors including geographic area, race/ethnicity, menstruation, whether a woman has given birth, and diet were all important in affecting PFAS levels.[132]

Clearly more study is needed on PFASs and potentially susceptible populations in the region and beyond. As noted in Box 3, the Agency for Toxic Substances and Disease Registry Biomonitoring of Great Lakes Populations program has been underway since 2010, with the initial phase involving studying susceptible populations in Michigan, Minnesota and New York. Preliminary results (but not exposure data) have been released, and groups of individuals were successfully recruited in all three states, including Detroit River anglers (80 percent non-Hispanic African-American), Fond du Lac community members in Minnesota (57 percent female), and anglers from New York state (83 percent non-Hispanic white), and including an additional group of Burmese immigrants. Actual biomonitoring data from the research will be forthcoming.[133]

Further research is needed on potential disproportionate exposures and effects due to PFASs among communities of color and in low-income communities. As has been noted recently in a broader review of environmental hazards and racial and socioeconomic disparities, most such studies have been cross-sectional (across a large population or area) and snapshot studies. Instead, there is a need for longer-term longitudinal studies tracking communities at the time of and after siting of hazardous waste or other facilities.[134] Concerning areas with existing facilities, available data on factors such as socioeconomic status and polluting facilities can be aggregated to provide a screening level assessment of potential disproportionate environmental exposures. A recent assessment done for Michigan through a Masters project at the University of Michigan found inequitable distribution of environmental goods and harms.[135]

APPROACHES FOR REDUCING HUMAN EXPOSURES TO PFASs

In general, reducing human exposures to PFASs or any other toxic chemical group can entail interventions at several points in the cycle noted in the infographic on pp. 24-25, including addressing sources, cycling in the environment, and behaviors that can reduce exposures, with the first and third approaches the most practical. As stated previously, for PFASs we must consider the exposure routes; while ideally exposure via all routes would be reduced or eliminated, there is obviously value in focusing resources on more significant routes. Legal and policy approaches to address the PFAS problem are summarized in the State Policy Tools to Address PFAS Impacts to Water Quality section starting on page 21, and several technical and related approaches to reduce exposures are summarized here.

One of the potentially most effective overall approaches to addressing PFASs is avoiding manufacture and use of the problematic chemicals in the first place. Thus, restrictions on use of particular chemicals (and potentially preventing use of a chemical altogether before it is even marketed, if available evidence suggests likely problems) is one viable option. Such restrictions at the federal level in the United States would be adopted under either the Toxic Substances Control Act or the Consumer Product Safety Act. Indeed manufacture of PFOS was phased out in the United States in the early 2000s, though this effort resulted from a voluntary agreement between the manufacturer and U.S. EPA,[136] rather than a formal regulatory ban by the agency. The agency has taken other actions under the Toxic Substances and Control Act related to PFASs, including adopting significant new use rules.[137] (See further discussion in the State Policy Tools to Address PFAS Impacts to Water Quality section on page 21.)

Additional approaches to reduce exposures to PFASs in the region can entail addressing PFASs in both wastewater and drinking water treatment. Neither type of process was historically designed to reduce PFASs. One of the challenges with PFASs, as previously noted, is varying physical-chemical characteristics of individual compounds, though many are more water soluble than other persistent organic pollutants. In the case of drinking water, standard steps in treatment (e.g. coagulation and sedimentation, filtration, disinfection) are not generally effective at controlling or destroying PFASs. More advanced treatment approaches such as activated carbon sorption, ion exchange, and high-pressure membrane filtration (e.g. reverse osmosis) can be effective at removing PFASs from source water.[138] Challenges with these techniques are the costs of installation and maintenance (in particular for smaller communities) and the need to dispose of the removed PFAS compounds.[139] Though technologies to destroy PFASs are under development, there is no routine technology in place to both remove and destroy the compounds in water treatment plants, indicating the need for further research and development.[140] As noted in the State Policy Tools to Address PFAS Impacts to Water Quality section on page 31, there are currently no requirements in place for water utilities to monitor or treat PFASs. An additional approach to removing PFASs is at point-of-use (i.e. in-home filters). In one test of a system in Washington County, Minn., a particular filter was generally effective at removing most PFASs to below detection limits,[141] but more research is clearly needed on a wider variety of treatment systems.

For fish and shellfish PFAS exposures, in addition to reducing sources to the environment, a longstanding approach used by agencies has included development of fish consumption advisories. Though federal governments (i.e. U.S. and Canadian) develop guidelines, fish consumption advisories themselves are developed by states, provinces and tribes. Developing such advisories requires having protocols in place, including monitoring data for individual water bodies. In some cases, advisories have been developed following findings of high levels of local contamination by PFASs, such as occurred around the former Wurtsmith Air Force Base in Michigan in 2010.[142] Elevated levels of PFASs in Lake Niapenco downstream of Hamilton International Airport in Ontario led to issuance of PFAS advisories, in particular for common carp.[143] Minnesota has been at the lead (among both Great Lakes states and nationally) in both monitoring for PFASs and issuing advisories, having started monitoring for PFASs in 2002, and having had fish consumption advisories in place for over a decade, including with over two dozen lakes listed due to PFOS currently.[144] Michigan has also had fish consumption advisories in place over the past decade, and as of 2019 has over 60 advisories in place (sometimes combined with other contaminants such as mercury), including Do Not Eat advisories for all fish species in three water bodies—Clark's Marsh (near Oscoda), most of the Huron River in southeast Michigan, and Beaver Dam Pond in southwest Michigan.[145]

A related issue is the potential for PFAS contamination of game. In Michigan, researchers sampled deer near the former Wurtsmith Air Force Base and found elevated PFAS levels, and the state issued a Do Not Eat advisory for deer taken within five miles of Clark's Marsh in Oscoda Township.[146] Given the lack of more comprehensive monitoring, it is not clear to what extent deer and other game are contaminated with PFASs, though some local monitoring of other wildlife (including muskrat) has been carried out in the same general location.

SUMMARY OF EXPOSURES, EFFECTS, EQUITY CONCERNS, AND POTENTIAL RESPONSES IN THE GREAT LAKES REGION

There has been a significant increase in research on exposures and potential health impacts in people to PFASs over the past two decades, but among general findings are the following:

- Multiple studies indicate that food ingestion is a major exposure route for the most common PFAS compounds, but in some cases other routes (including tap water and house dust) can also be significant, and these profiles will likely be different for individuals living near PFAS-contaminated sites.
- There have been limited studies on PFAS exposures and potential effects among populations in the Great Lakes region, though research in Wisconsin indicates fish consumption (including local fish consumption) can be an important exposure route.
- Effects associated with PFASs have been explored both through laboratory animal studies and multiple epidemiology studies, and effects with good documentation include testicular and kidney cancers associated with contamination at a nearby industrial site, immune system effects, and metabolic impacts, in particular concerning elevated total cholesterol and "bad" cholesterol.

On the question of PFASs and environmental equity and justice, one study documented elevated exposures to two PFASs in middle age African-American women compared to white women in southeast Michigan. Larger-scale studies have found that hazardous waste sites are more likely to be found near communities of color and low-income communities, but further research is needed to provide a more comprehensive picture of potential disproportionate exposures to PFASs in the region.

Approaches to reducing PFAS exposures in people include reducing the primary sources of PFASs (i.e., at chemical or product manufacturing sites), cleaning up contaminated sites, treating wastewater and drinking water, and issuing advisories, including for fish and game. Work in all of these areas is underway (see discussion below on legal and policy approaches). However, further research and monitoring would help inform work going forward, including more research on a wider range of PFASs, more monitoring of drinking water (both public supplies and private wells), expanded human biomonitoring (including susceptible populations), development of economical technologies that can both remove and destroy PFASs in drinking water, and comprehensive inclusion of PFASs in fish tissue monitoring and advisory programs (including potentially through a common protocol, as done previously for PCBs).

In summary, the scientific community has significantly increased knowledge about PFASs in the Great Lakes region in the past two decades, and combined with other studies nationally in the United States and elsewhere, there is increasing understanding of historic and ongoing sources, environmental levels, human exposures and effects, ecological exposures and effects, all of which are helping to inform potential technical and other approaches to address the problem. While scientists continue to learn more about how to most effectively address PFASs in people and the environment, several viable policy tools currently exist that states can utilize now to address PFASs in the Great Lakes region.

State Policy Tools to Address PFAS Impacts to Water Quality

As with any toxic chemical, numerous federal and state laws regulate or are capable of regulating PFASs. Some laws target drinking water safety; others address protection of water bodies and wildlife that depend on them; while still others focus on reporting and information sharing. Given slower movement on the PFAS issue at the federal level until recently, and the opportunities for states to make significant progress on their own, the focus of recommendations here is mostly on state actions, following a review of federal laws and programs. This section analyzes how water quality, cleanup, and public drinking water laws and policies currently address pollutants like PFASs, and recommends changes to those state laws and policies.

Generally, environmental laws[147] that regulate PFASs address the following: the use of PFASs in various manufacturing and industrial processes; the planned discharge of PFASs into the air, soils, or water; the disposal of, and cleanup of, discarded PFASs; and reporting on PFAS quantities. Such environmental laws typically task an administrative agency with development and enforcement of specific standards.

For example, at the federal level, the Toxic Substances Control Act regulates the entry of chemicals into the market and their use once there. Through the Toxic Substances Control Act, EPA can limit, restrict, condition, or ban the use of chemicals that pose an unreasonable risk to human health or the environment. The Toxic Substances Control Act applies to manufacturers, processors, and other kinds of chemical users. EPA has already regulated PFASs through this law, though not extensively. There are approximately one thousand PFAS chemicals on the existing chemical inventory, including chemicals not currently marketed in the United States.[148] In the last 20 years, the EPA has overseen the voluntary elimination of the production and use of PFOS and PFOA.[149] EPA has issued Significant New Use Rulemakings regarding the manufacturing of certain PFASs and their use in carpets.[150] In 2015, the EPA proposed a Significant New Use Rulemaking for Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances that would require 90 days advanced notification before use of PFOA and related chemicals.[151] Though EPA has taken some type of action on over 300 PFAS chemicals over the past 15 years,[152] it is not clear to what extent the actions have resulted in reduced uses, releases, and exposures for all the chemicals involved.

Other laws are focused on disseminating information about the risk posed by chemicals like PFASs. The Emergency Planning and Community Right to Know Act (EPCRA) functions to alert the public about toxic pollution. One aspect of EPCRA is the Toxics Release Inventory. The Toxics Release Inventory "inform[s] persons about releases of toxic chemicals to the environment; [ ] assist[s] governmental agencies, researchers, and other persons in the conduct of research and data gathering; [and,] [ ] aid[s] in the development of appropriate regulations, guidelines, and standards."[153] The EPA has thus far not added any PFASs to the Toxics Release Inventory, though many groups have called for inclusion of the entire class of PFASs.[154]

The focus of the remainder of this report is on those environmental law frameworks that the federal government initiates but that states, through their own laws, usually implement and enforce either in lieu of the federal government or alongside it. With regard to PFASs, the most obvious of those legal frameworks are the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

There are two reasons to focus on these laws. First, dozens of environmental laws are capable of addressing PFASs, so it was necessary to create a manageable scope. Second, at the moment there are few enforceable federal PFAS standards that limit or guide what states can do. Therefore, states that have implemented their own versions of federal laws have ample room to act on PFASs.

Certain state legislators and regulators argue that they should wait for the federal government to act first on PFASs. It is encouraging that Congress recently proposed a number of bills as part of the National Defense Authorization Act that would address PFASs.[155] However, even though Congress is trying to act on PFASs, there are still good reasons why states should move quickly and decisively. First, some of the federal bills that may be enacted do not directly influence state policy. Some, for example, address federal military installations and seek to add PFASs to the Toxic Resource Inventory. Both efforts are positive, but they are both almost exclusively within the federal government's jurisdiction. Therefore, they do not shape what a state needs to do on drinking, surface, or groundwater standards. Second, even where a bill shapes state policy by creating a federal floor, it provides EPA up to two years to implement standards. States simply cannot wait that long. While action on PFASs by Congress is desperately needed, states should not regard it as a substitute for state-level action.

Finally, where appropriate, recommendations are made here that address the environmental injustices that stem from PFAS pollution. PFAS pollution harms everyone, but there can be disproportionate harm to vulnerable communities such as communities of color and communities with lower than average household income levels, if they are living near PFAS-contaminated sites or otherwise have elevated exposures. For example, when there is PFAS pollution of groundwater that serves as a source of private well water, economically distressed communities have fewer resources to respond quickly and adequately. Decisions to incinerate sewage sludge that contains PFASs often directly affect communities of color residing within the zone of air pollution impact. Therefore, every time a state or municipality considers how to change or implement a policy with regard to PFASs, it must sincerely incorporate those vulnerable communities into the decision-making process and must make decisions that do not disproportionately impact those communities.

A summary of key provisions of several laws addressing PFASs is provided here, with key recommendations provided at the start of individual sections.

Clean Water Act

Regulation through the Clean Water Act primarily addresses protection of streams, lakes, and wetlands through limiting the pollution that enters them. The vast majority of Clean Water Act implementation and enforcement happens at the state level. Although certain actions taken by EPA can help, the focus here is on what states can do in the absence of EPA action.[156]

National Pollutant Discharge Elimination System (NPDES) permitting is intended to ensure compliance with water quality standards. Water quality standards consist of protected water body uses, water quality criteria (narrative or numeric), and an anti-degradation policy.[157] States that wish to implement and enforce the Clean Water Act must have water quality standards in place.

For protected uses, states identify categories of water body use to protect through Clean Water Act implementation. Often, these uses relate to recreation, propagation of fish and shellfish, protection of wildlife, public water supply, agriculture, and industrial.[158] For anti-degradation, states must have a policy that protects existing uses and, where it exceeds the levels necessary to protect a use, existing water quality.[159]

Water quality criteria are the measure of when a water body use is being protected.[160] They can be narrative or numeric in format. The Clean Water Act requires EPA to develop recommended criteria, but states ultimately develop their own enforceable criteria through their versions of the Clean Water Act.

Narrative criteria come in many forms. In Ohio, for example, one of the narrative criteria is that "[t]o every extent practical and possible as determined by the director, these waters shall be [ ]...[f]ree from substances entering the waters as a result of human activity in concentrations that are toxic or harmful to human, animal or aquatic life...."[161] In Michigan, one of the criteria declares, in part, that the "surface waters of the state shall contain no taste-producing or odor-producing substances in concentrations [...] which impair the palatability of fish as measured by test procedures approved by the department."

Numeric criteria are expressed as maximum allowable levels. For example, if the criterion for chloride is 250 mg/L, that means the concentration of chloride in a water body must remain below 250 mg/L if the most chloride-sensitive use is to remain protected.

States issue National Pollutant Discharge Elimination System permits to those who wish to discharge pollutants into water bodies. NPDES permits contain various conditions and requirements, such as monitoring and limits pollutant concentrations, that ensure compliance with water quality standards.

With regard to PFASs, there are several Clean Water Act opportunities that states can exercise. Those opportunities include:

- Setting water quality criteria to protect the health of people and wildlife;
- Evaluating impaired waters and setting pollution limits through Total Maximum Daily Loads (TMDLs);
- Establishing strong requirements through National Pollutant Discharge Elimination System (NPDES) permitting;
- Curtailing pollution before it gets into sewage treatment plants through the Industrial Pretreatment Program and regulation of industrial discharges into sewer systems; sewage treatment plants (or publicly

owned treatment works) and the regulation of sludges or biosolids created by them.

NUMERIC CRITERIA, IMPAIRMENT, AND TMDLS

States through legislation or rulemaking should develop numeric water quality criteria for PFASs of concern.

The development of water quality criteria for PFASs of concern[162] opens up the ability for agencies to designate water bodies as PFAS-impaired. Once designated, the agency can then prepare a plan to remedy the impairment. The federal EPA has not established recommended water quality criteria for PFASs, nor do they plan to do so sooner than 2021.[163] States can and should establish them through their own rulemaking.

Where a water body contains a pollutant at a level that exceeds the numeric criterion level for that pollutant, the state must deem that water body to be impaired and then address the impairment. The Clean Water Act requires states to identify water bodies that are impaired.[164] The state agency must then craft a plan to reduce pollution into the impaired water body. That plan usually results in the creation of a Total Maximum Daily Load. A Total Maximum Daily Load (TMDL) is the "calculation of the maximum quantity (or load) of a pollutant that may be added to a water body from all sources [...] without exceeding the applicable [water quality standard] for that pollutant."[165] With regard to the pollutant that caused the impairment, a TMDL allows regulators to adjust effluent limits in NPDES permits and to address other sources of pollution.[166] Even before a TMDL or other pollution-reduction plan is established, impairment designation impacts NPDES permitting by significantly limiting the addition of any pollutant that has caused the impairment.[167]

For PFASs, establishing numeric water quality criteria is important for the purpose of impairment designations. With numeric criteria, the agency can know whether a water body has too much PFASs and how to craft and implement a TMDL.

States may be able to develop a criterion for the class, expressed as a concentration of all the PFASs combined. Usually, however, states develop a criterion for individual pollutants.

Michigan is the only Great Lakes state to date to have promulgated enforceable numeric criteria for certain PFASs in surface waters. The state has assigned water quality values for PFOA and PFOS based upon various designated-use determinations, including potential use as a source of human drinking water and use as habitat for aquatic wildlife.[168] The most stringent limits apply to receiving waters protected as a source of drinking water, with PFOA regulated to a maximum concentration of 420 ppt and PFOS regulated to a maximum concentration of 11 ppt. The regulation sets less stringent limits for surface receiving waters not protected as a drinking water source.[169] It also establishes other criteria to protect aquatic life, including aquatic maximum values to protect surface waters used as habitat for wildlife.[170] The state can also develop wildlife values specifically designed to protect against bioaccumulative chemicals of concern, but wildlife values for PFAS compounds have yet to be developed in Michigan.[171]

While no other Great Lakes states have established enforceable PFAS concentration limits for surface waters, Minnesota has set limits for specific water bodies.[172] These apply to the designated receiving waters, but not to the state's surface waters as a whole. Wisconsin has pledged to consider the development of potential criteria for PFAS concentrations in the surface waters of the state.[173] However, it has predicated that determination upon the outcome of the state's ongoing process to develop PFAS concentration limits for groundwater with potential use as drinking water.[174]

Table 4 on page 26 provides a summary of current water quality criteria for the Great Lakes states.

NPDES PERMITTING

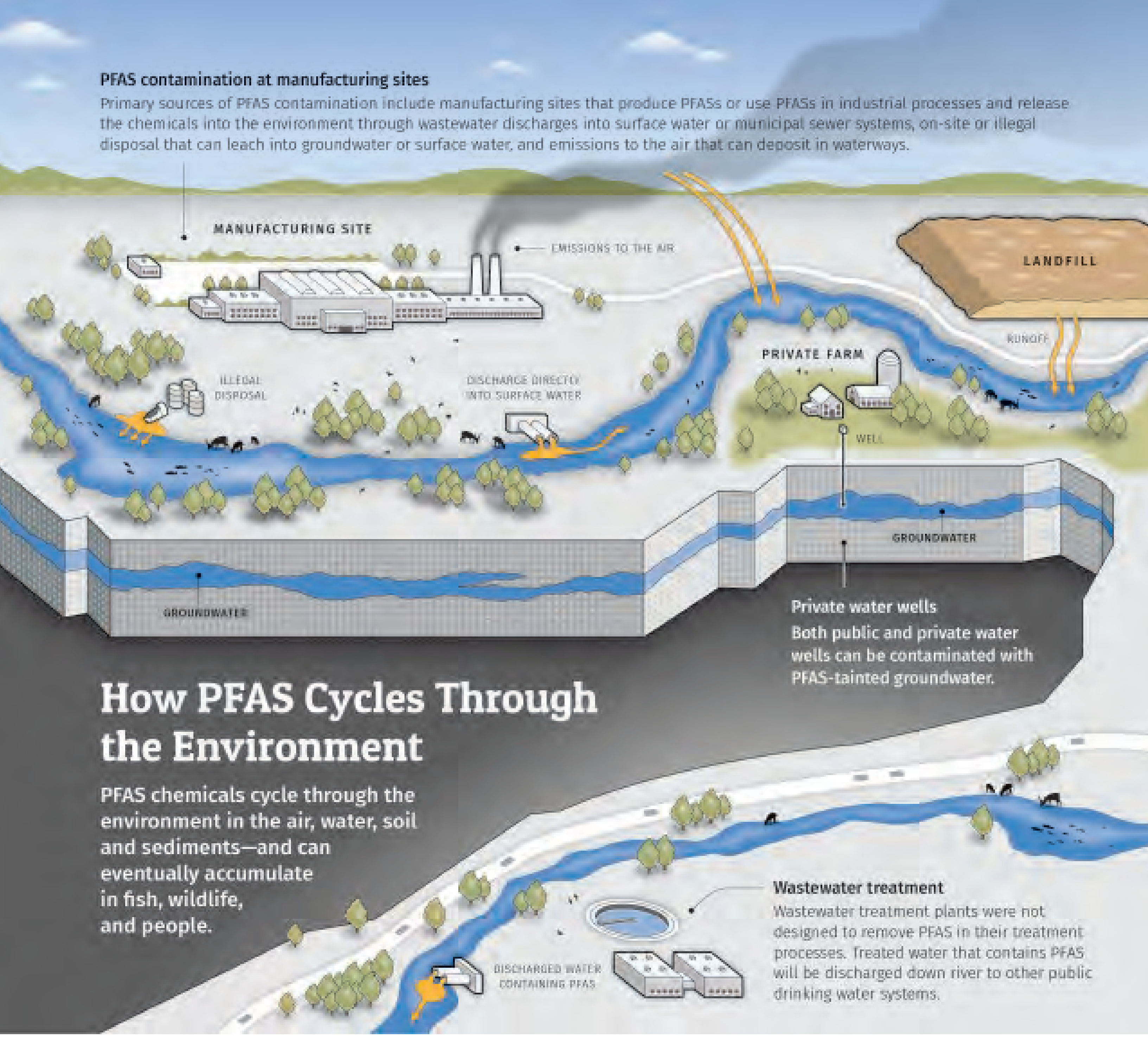
States, though the permitting process, should include in NPDES permits effluent limits and monitoring requirements for PFASs.

NPDES permits must ensure compliance with water quality standards. Permits can contain both substantive limits as well as monitoring requirements.

There are primarily two kinds of substantive effluent limits: technology-based and water quality-based. Water quality based effluent limits (WQBELs) apply when technology-based effluent limits (TBELs) alone cannot ensure compliance with water quality standards.

Technology-based Effluent Limits

TBELs apply to individual pollutants. TBELs can derive from either effluent limitation guidelines or the exercise of best professional judgment. Effluent limitation guidelines are created for industry groups based on waste stream composition as well as the availability and cost of treatment technology. Where an effluent limitation guideline exists, the agency must incorporate the relevant technology-based limits into the NPDES permit.[175] Where there is no effluent limitation guideline



Solutions to Prevent and Remediate Toxic PFAS Contamination

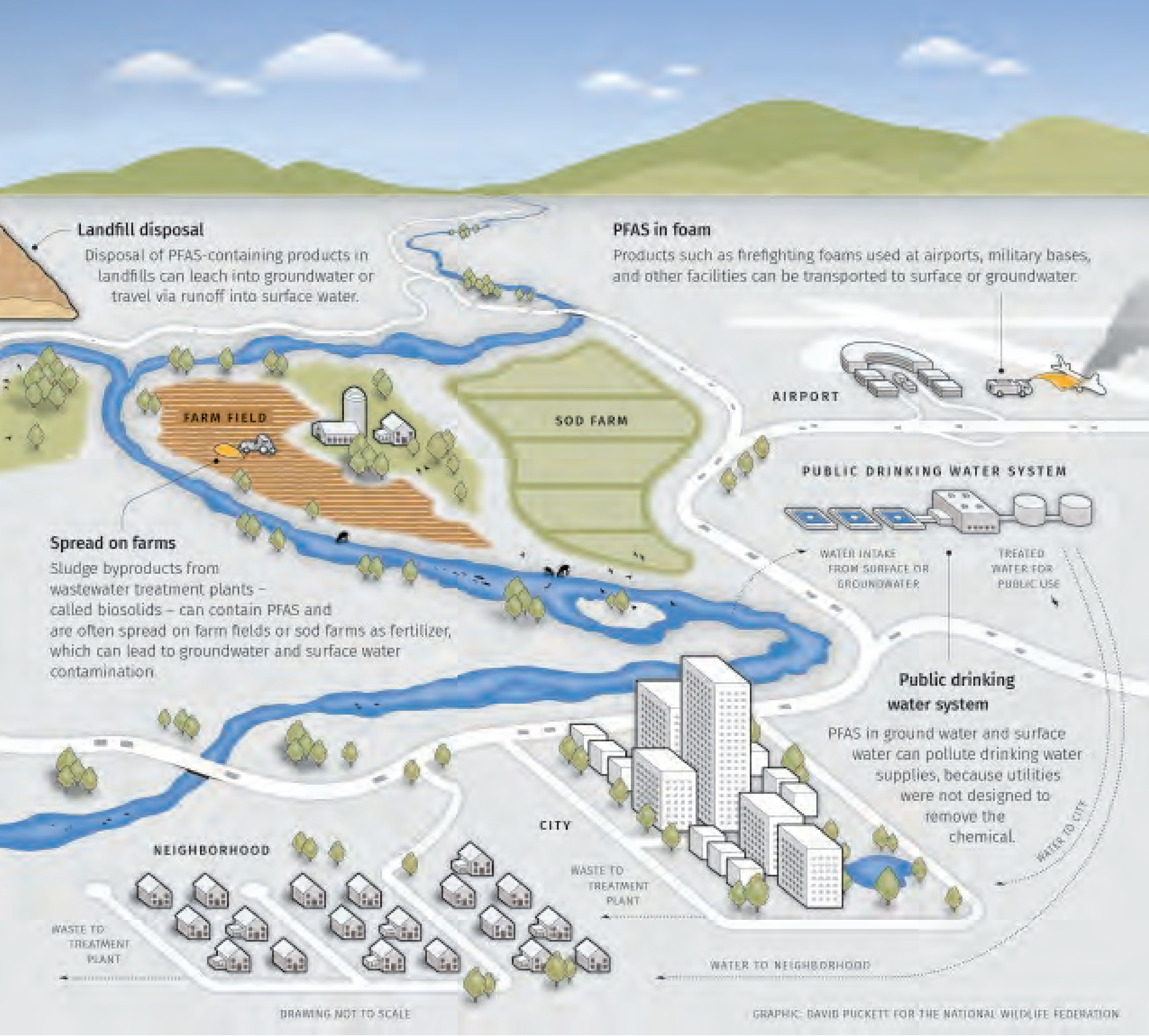
State and federal governments can play an essential role in putting forward common-sense solutions to confront the PFAS crisis to protect the health of people and wildlife. Government can:

1. Phase out PFAS chemicals in industrial processes

- Businesses can voluntarily change their manufacturing processes to eliminate PFAS from their operations to protect the environment and human health.
- The U.S. EPA can also limit or stop the use of chemicals under the Toxic Substances Control Act.

2. Limit pollution from industrial and other discharges

- Under the Clean Water Act, federal and state governments can establish protections to limit industrial discharges of PFAS into the environment.
- States can set numeric standards for how much PFAS is allowable in lakes and streams.
- Industries are then required to treat their wastewater and remove PFAS, based on National Pollutant Discharge Elimination System permits.
- States develop pollution-reduction plans – known as Total Maximum Daily Loads – for water bodies not meeting water quality standards for PFAS.



3. Set clean drinking water standards

- The U.S. EPA, under the Safe Drinking Water Act, and state governments by legislative or executive action, can set drinking water standards to limit PFAS exposure via public drinking water supplies.
- Local water treatment plants can remove dangerous PFAS from drinking water.
- Local water treatment plants monitor to make sure clean water goals are being met, and the state government evaluates the results.

4. Invest in local drinking water and wastewater treatment plants

- Federal government can increase funding to repair and build water infrastructure.
- States provide state funding as well, and set investment priorities.
- Local communities make needed upgrades to wastewater and drinking water treatment facilities.

5. Invest in cleanup of contaminated sites

- Federal and state governments can designate sites as contaminated hot spots under laws like the Comprehensive Environmental Response, Compensation, and Liability Act (known as Superfund).
- Polluters pay to restore contaminated sites.
- State and federal government can also invest funding to remediate pollution, such as PFAS.
- Designation of certain PFAS as hazardous allows government and private parties to conduct and pay for cleanup.

TABLE 4. Summary of Ambient Water Quality Criteria, Drinking Water Standards and Guidance, and Groundwater and Soil Cleanup Standards for the Eight Great Lakes States[a]

	CWA—SURFACE WATER	SWDA—DRINKING WATER	CERCLA—GROUNDWATER AND SOIL
Michigan	**Drinking Source** **PFOS: 11 ppt** **PFOA: 420 ppt** **Non-Drinking Source** **PFOS: 12 ppt** **PFOA: 12,000 ppt**	Advisory Guidance PFNA: 6 ppt PFOA: 8 ppt PFOS: 16 ppt PFHxS: 51 ppt GenX: 370 ppt PFBS: 420 ppt PFHxA: 400,000 ppt	**Groundwater** **PFOS: 12 ppt** **PFOA: 12,000 ppt** **Soil—Human Drinking Water Interface** **PFOS: 220 ppt** **PFOA: 350,000 ppt** **Soil—No Human Drinking Water Interface** **PFOS—240 ppt** **PFOA—10,000,000 ppt**
Minnesota	**Limits for Specific Water-Bodies Only**	**Health-Based Values** **PFOS: 15 ppt** **PFOA: 35 ppt** **PFHxS: 47 ppt** **PFBS: 2,000-3,000 ppt** **PFBA: 7,000 ppt**	**Soil** **PFOA: 330,000 ppt** **PFOS: 1,700,000 ppt** **PFBS: 30,000,000 ppt** **PFBA: 63,000,000 ppt**
Wisconsin	Under Consideration	In-Process	Groundwater—Enforcement Standard PFOS and PFOA: 20 ppt Groundwater—Preventative Action Limit PFOS and PFOA: 2 ppt **Soil—Non-industrial** **PFOA & PFOS: 1,260,000 ppt** **PFBS: 1,260,000,000 ppt** **Soil—Industrial** **PFOA & PFOS: 16,400,000 ppt** **PFBS: 16,400,000,000 ppt**
New York	X	Proposed MCL PFOS: 10 ppt PFOA: 10 ppt	X
Pennsylvania	X	Under Consideration	X
Illinois	X	X	X
Indiana	X	X	X
Ohio	X	X	X

a: As discussed in text or endnotes, with citations in endnotes.
Bold = Finalized   Non-bold = In-Process   X = No relevant standard in place or in development

for a particular pollutant, the agency must exercise its best professional judgment to develop a TBEL.[176]

There are no federal effluent limitation guidelines that address PFASs, though the federal EPA is currently considering the issue.[177] Absent applicable effluent limitation guidelines, state permit writers must exercise their best professional judgment to develop TBELs.[178] For example, were an electroplating facility to propose a direct discharge to a waterbody that would contain a material amount of PFOA, even in the absence of effluent limitation guidelines, the agency would have to exercise its best professional judgment to create and apply a TBEL to limit PFOA.

Water Quality-based Effluent Limits

WQBELs apply to pollutants when TBELs either are not applied or alone will not ensure compliance with water quality standards.[179] WQBELs are based on the needs of specific receiving water bodies and do not take cost or feasibility into account. Regarding the electroplating facility example above, if in spite of any particular TBEL or the lack of a TBEL the discharge were to threaten attainment of water quality standards, the agency would have to create and apply WQBELs sufficient to protect those standards.

While a permit writer can develop WQBELs based on narrative or numeric criteria, it is far easier to develop WQBELs with numeric criteria in place. Therefore, apart from impairment and TMDLs, the existence of numeric criteria also facilitates WQBEL development for PFASs. After exercising their best professional judgment to develop PFAS TBELs, state permit writers must also consider development of PFAS WQBELs where needed.

Monitoring

Regardless of the need to apply TBELs or WQBELs, permit writers have great latitude to require monitoring of various pollutants. While monitoring is done to ensure compliance with effluent limits, it is also done to characterize effluent.[180] NPDES permit writers should exercise their authority to require monitoring for PFASs whenever they suspect that PFASs will be in the waste stream.

Any effluent limit in a NPDES permit must be accompanied with a way to measure compliance. The permittee must be able to measure the concentration of PFASs in the effluent so that it, the agency, and the public can know whether the permittee is complying with the PFAS effluent limit. Normally, permit writers include EPA-approved analytical methods in the permit.[181] However, where there is no EPA-approved methods, the permit writer can select an alternative method.[182]

In summary, with regard to NPDES permitting:

- In the absence of applicable effluent limitation guidelines, agencies must include TBELs for PFASs in NPDES permits through the exercise of the permit writer's best professional judgment
- Where appropriate, agencies must include WQBELs for PFASs in NPDES permits based on narrative or numeric criteria and the overall need to ensure attainment with water quality standards
- Agencies must include monitoring requirements where PFASs of concern are expected to be present in the waste stream in material concentrations

PUBLICLY OWNED TREATMENT WORKS AND THE INDUSTRIAL PRETREATMENT PROGRAM

In NPDES permits for public wastewater treatment plants, where PFAS may be in the effluent, agencies should require monitoring for PFAS.

Public wastewater treatment plants, through legislation or rulemaking, should apply specific monitoring and pretreatment requirements to industrial users that are expected to discharge PFASs to the treatment facility.

Publicly owned treatment works (or wastewater treatment plants owned by a state or municipality) collect and treat municipal wastewater. Mostly, the wastewater reaches the treatment plant through a sewer network, although certain wastewaters are delivered by truck or rail. Municipal wastewater consists mainly of domestic wastewater from homes and businesses, but industrial waste streams can also contribute.

The treatment infrastructure at the plants is designed to address domestic wastewater. For that reason, agencies and sewage treatment plants administer the Industrial Pretreatment Program which requires industrial users to pretreat their industrial wastewater before discharging it to the treatment facility. Without pretreatment, industrial chemicals such as PFASs may either bypass or interfere with wastewater treatment systems in violation of the law.

In Wixom, Mich., there were significant issues with PFASs from industrial user wastewater flowing untreated through the sewage treatment facility and then being discharged by the utility into a small stream.[183] A manufacturing facility had been placing enough PFOS into the sewer system and through the sewage treatment plant that the stream at one point contained as much as 5,500 ppt, which is more than 450 times the applicable surface water quality criterion. In Wisconsin, the Department of Natural Resources has raised alarm bells about the industrial contributions of PFASs to sewage treatment plants.[184] The

Ohio Environmental Protection Agency has also been investigating PFASs in sewage treatment plants.[185]

For sewage treatment plants that have a pretreatment program, the state agency regulates and issues NPDES permits to them for their direct discharge to a natural water body. Those NPDES permits contain monitoring and effluent limits as well as other conditions that are specific to the plants. For large enough sewage treatment plants that accept industrial wastes, those limits and conditions may also pertain to various toxic chemicals.

While the state agency focuses on the sewage treatment plant itself, the treatment plant regulates and issues indirect discharge permits to the industrial users within their jurisdiction who discharge wastewater to the plant. Sewage treatment plants do this through implementation of minimum federal pretreatment standards as well as their own site-specific standards.[186] The minimum federal pretreatment standards comprise general pretreatment requirements and categorical pretreatment standards.

The most important general pretreatment requirements are that industrial sources of wastewater cannot discharge pollutants to a public sewage treatment plant that will cause “pass-through” or “interference.”[187] Pass-through occurs when a pollutant enters the sewage treatment plant, generally avoids treatment, and causes a violation of the facility’s NPDES permit. Interference occurs when the pollutant enters the sewage treatment plant and interferes with its treatment process.

Categorical pretreatment standards are the sewage treatment plant equivalent of effluent limit guidelines.[188] Categorical pretreatment standards establish pollutant limits for certain pollutants based on the category of industrial user.

The federal government establishes the general pretreatment requirements and the categorical pretreatment standards. The general pretreatment requirements are not specific to any particular toxic chemical. None of the categorical pretreatment standards addresses PFASs at the moment.

Sewage treatment plants establish what are called local limits to implement the minimum federal standards. Local limits often take the form of ordinances or resolutions depending on whether the treatment facility is public or private. Sewage treatment plants can create local limits that go above the federal floor (and, per the discussion below, may be able to evade no stricter laws as these are local, not state, standards). For example, there are categorical pretreatment standards that apply to the electroplating of common metals industry, but they do not address PFASs.[189] A sewage treatment plant receiving a discharge from a common metals electroplater would be better protected were it to add local limits for PFASs that would require the electroplater to monitor for PFASs and perhaps also pretreat its wastewater to achieve a numeric PFAS limit.

When issuing NPDES permits to sewage treatment plants, state agencies should include monitoring requirements for PFASs of concern. They should also expressly require the facility to ensure that its local limits address PFASs. Monitoring for PFASs helps the treatment facility decide which kinds of local limits to develop and to know whether they may have industrial users discharging PFASs in a way that is not being addressed by the local limits.

Sewage treatment plants with pretreatment programs must amend their local limits to better address PFAS pollution. Local limits should require industrial users to engage in robust PFAS monitoring to identify PFASs of concern.[190] Treatment facilities should also include numeric PFAS limits in industrial user permits. Michigan has valuable materials on addressing PFASs through an Industrial Pretreatment Program.[191]

From an equity perspective, it is doubly important for sewage treatment plants to focus on those who discharge PFASs into the system because many plants are either arms of local government or private organizations with government functions. Every dollar the public treatment facility spends on responding to PFASs is collected from the local residents through taxes or fees. It is unfair for residents to bear the full cost burden of PFAS monitoring and treatment when industrial users are creating those costs. For example, whether industrial users do the monitoring themselves or whether the treatment facility does the monitoring, the more equitable approach would be for the industrial users to bear the cost of the monitoring. Otherwise, sewage treatment plants will essentially have to charge local residents for PFAS monitoring of industrial user effluent. Forcing the plant to bear the cost disproportionately impacts vulnerable communities with lower average household incomes.

BIOSOLIDS

States must condition use of biosolids that may contain PFASs and require pollution control standards where necessary.

During the treatment process sewage treatment plants produce sewage sludge or biosolids. The U.S. EPA regulations have established minimum standards for biosolids to protect the health of people and the environment.[192] Based on the regulations, biosolids can be land applied as fertilizer, disposed of in landfills or surface disposal sites, or incinerated. The regulations contain numeric limits for certain kinds of pollutants commonly found in biosolids. These limits vary depending on how one is using or disposing of the biosolids and they apply mainly to metals and nutrients. States are free to implement and enforce their own biosolids program so long as it is at least as stringent as federal EPA's.

Current federal biosolids regulations do not address PFASs, though states should begin tackling the problem in their programs. For land application, land disposal, or incineration, states can establish monitoring programs as well as science-based numeric limits. With regard to land application and disposal, the focus would be the impact of PFASs on aquifers and crops.

With regard to incineration, the concern would be the impact of PFASs released or byproducts on human health and on surface water bodies following atmospheric deposition. With incineration, apart from the standard considerations (such as the need for high temperatures to achieve destruction of PFASs),[193] there must also be a focus on equity and environmental justice. Land application of biosolids will often take place in rural areas, some of which may be low-income. Incineration by sewage sludge incinerators will often take place in urban areas with high minority populations and concentrations of people who are poor.[194]

Remediation or Cleanup Laws

States should designate PFASs of concern as hazardous for purposes of their cleanup laws, and should develop enforceable cleanup criteria.

Rather than prevent pollution, cleanup laws call on polluters to clean up the pollution they have already caused. The Comprehensive Environmental Response, Compensation, and Liability Act or CERCLA is the principal federal law that governs cleanup. CERCLA, also known as Superfund, mainly addresses the release of hazardous substances into the environment.

CERCLA can also address the release of pollutants or contaminants that are not hazardous substances when such a release may pose an imminent or substantial danger to public health or the environment.[195]However, because far fewer enforcement tools are available to enforcing agencies who seek exclusively to address pollutants or contaminants that are not hazardous substances, agencies seldom do it. More tools are available where pollutants or contaminants are present along with hazardous substances.

The question of what constitutes a hazardous substance is fraught with nuance and exception. Basically, instead of defining specific hazardous substances under Superfund, the law incorporates as hazardous substances various chemicals and wastes from other laws such as the Clean Water Act and Solid Waste Disposal Act.[196] Most of these hazardous substances are compiled in a CERCLA rule table.[197] Many are individual elements or compounds, such as arsenic or calcium hypochlorite. Some are waste streams that contain multiple elements and compounds, such as wastewater treatment sludges from electroplating operations. A waste is considered a hazardous substance so long as it contains a listed element or compound even if the waste stream is not listed.[198]

To address a release of a hazardous substance, CERCLA applies liability broadly to various kinds of potentially responsible parties ("PRPs"), including those who own or operate facilities where a release occurs, those who at the time of disposal owned or operated the facility, and those who arrange for disposal or treatment of the hazardous substance. When there is a release of a hazardous substance, EPA can order the responsible parties to perform cleanup. EPA or private parties can also perform the cleanup themselves and then sue the responsible businesses or industries for compensation. For time-sensitive cleanups or for times when polluters cannot be found or cannot pay, the federal EPA has the ability to use money from a trust fund commonly called "Superfund" to perform the cleanup.

How much cleanup is adequate? CERCLA itself does not have many specific cleanup standards. Instead, CERCLA requires that cleanups comply with "applicable, relevant, and appropriate requirements."[199] These cleanup requirements draw from state and federal environmental and public health standards. For example, for groundwater that is or may be a drinking water source, CERCLA requires remediation that achieves the relevant Safe Drinking Water Act maximum contaminant levels.

States are free to enact and enforce their own version of CERCLA. States can define their own scope of PRP liability, list of hazardous substances, and set of cleanup standards. Often, states create cleanup standards that apply to soils, groundwater used for public or private water supply, and groundwater that vents or discharges to a surface water body.

To address PFASs, states have various options with regard to cleanup laws. Much depends on the specifics of state law, though most state laws adopt something like the basic federal cleanup framework described above.

First, states can designate all PFASs or certain PFASs of primary concern as hazardous substances. Designation as hazardous substances would serve to trigger cleanup enforcement. One way to do this is to designate individual pollutants as hazardous substances. For example, Michigan designates specific "spent halogenated solvents" including 1,1,1-trichloroethane as hazardous substances.[200] States can do the same with one or more PFASs. Another way is to designate as hazardous substances waste streams that are known to contain PFASs and other dangerous chemicals. Designating a waste stream as hazardous would allow states to be industry-specific, whereas designating PFASs themselves as hazardous would open up liability to a wider variety of actors.

Second, rather than rely on cleanup standards from other legal frameworks, states can develop specific numeric cleanup criteria that would apply to PFASs. If PFASs were present in, say, a wastewater treatment sludge from an electroplating operation, and the state had cleanup criteria for PFASs, then the violator would have to clean up the PFASs until the levels no longer exceeded the relevant cleanup criteria. Also, when federal CERCLA applies and the EPA must identify cleanup requirements, state cleanup criteria can function as cleanup requirements (or "applicable, relevant, and appropriate requirements").

Cleanup criteria for PFASs are especially relevant with regard to private water wells. Millions of Great Lakes residents rely on private wells that draw on groundwater for their water supply. Unlike the Safe Drinking Water Act which regulates public water systems, there are no laws that specifically and comprehensively address the issue of groundwater pollution and private well protection. Cleanup laws can help address the problem with enforceable PFAS criteria. Take, for example, a release to groundwater of a hazardous substance that contained PFASs. If the cleanup criterion were 10 ppt for PFASs in groundwater that could be used for private water wells, then depending on the state law, the violator might have to ensure either that the groundwater PFAS levels were reduced below the criterion or that the private water well owner received treatment technology or access to an alternative water supply.

Michigan, Minnesota, and Wisconsin have established environmental remediation standards for sites with PFAS contamination. All three states have developed soil cleanup standards, while Michigan has also chosen to apply its surface water quality values as the applicable cleanup standard for the state's groundwaters.[201] Michigan's PFAS cleanup standard for soils is directly tied to this groundwater standard and is designed to ensure that soil contamination will not contribute to impermissible levels of PFASs in groundwater.[202] Wisconsin has also recently issued a set of recommended groundwater standards for PFOA and PFOS, and is now initiating a formal rule-making process to codify these standards.[203]

Minnesota's soil cleanup criteria were most recently updated in 2016, and establish advisory limits for PFOA, PFOS, PFBA, and PFBS.[204] These standards appear to function as guidance values to limit legal liability for actors engaged in voluntary clean-ups of contaminated sites.[205] Wisconsin has established soil residual contaminant levels for five PFAS compounds including PFOA and PFOS based upon whether the remediation site has an expected future use as an industrial or residential site.[206] These residual contaminant levels were calculated using EPA regional screening levels, and are based on a direct-contact pathway.[207] Unlike Michigan, Wisconsin has not established a groundwater-protective soil residual contaminant levels for these PFAS compounds.[208] Table 4 provides a summary of current cleanup criteria for the Great Lakes states.

The main takeaway is that clear, enforceable cleanup criteria must be in place. Designating PFASs as hazardous substances is a good start, but without enforceable cleanup criteria, the designation may not amount to much.

Safe Drinking Water Act

The Safe Drinking Water Act, first signed into law in 1974, is the main U.S. law addressing drinking water contamination. It includes a number of provisions, including development of drinking water standards for public water systems, a source water protection program, and a funding program for states to support municipalities' drinking water infrastructure.

DRINKING WATER STANDARDS FOR PFASs

States, through legislation or rulemaking, should develop enforceable PFASs drinking water standards for public water systems.

Under the Safe Drinking Water Act framework, there are two ways to regulate a chemical. An agency can either establish a maximum contaminant level (MCL), or it can adopt a treatment technique. Where it is "economically and technologically feasible to ascertain the level of [] [a] contaminant" in a water system, agencies set MCLs.[209] The MCLs are based on maximum contaminant level goals ("MCLGs"), which are the levels at which no known or anticipated health effects occur while allowing for a margin of safety.[210] MCLs can deviate from MCLGs because cost can be taken into consideration. Where there is a lack of technological or economic feasibility, instead of an MCL agencies select a treatment technique that sufficiently reduces the contaminant level.

The federal Safe Drinking Water Act does not currently regulate PFASs. Though various states have proposed them, there are only two states that currently have an enforceable drinking water standard. In New Jersey, the MCL is 13 ppt for PFNA.[211] In Vermont, there is a combined limit of 20 ppt for five PFAS compounds: PFOA, PFOS, PFHxS, PFNA, and PFHpA.[212] New Hampshire's, which will be effective in October 2019, has established MCLs for PFOA (12ppt), PFOS (15ppt), PFHxS (18ppt), and PFNA (11ppt).[213]

Among Great Lakes states, Minnesota was the first to develop advisory guidance standards for PFAS concentration limits in drinking water. The state has established a combination of health-based values and health-risk limits for five PFAS compounds, including standards for PFOA and PFOS that are more rigorous than the EPA's advisory levels of 70 ppt.[214] Michigan is aggressively pursuing development of legally-binding MCL standards, which it hopes to finalize by early 2020.[215] As an interim step toward this goal, the state recently issued a set of proposed health-based values for seven PFAS compounds, which it aims to translate into law by April 2020.[216]

Other Great Lakes states are at various stages in the process of developing PFAS drinking water standards. In late 2018, the New York State Drinking Water Quality Council recommended that the state's Department of Health adopt MCLs for PFOA and PFOS—at 10 ppt for each.[217] The New York Health Commissioner has recently begun the process of initiating a formal rulemaking process to codify these limits into law.[218] Wisconsin's Department of Health Services is in the process of developing health-based groundwater quality standards for PFOA and PFOS.[219] Pennsylvania announced in February 2019 that in the absence of federal action by the EPA to set MCLs for PFASs, the state will work toward setting its own legally-enforceable MCLs.[220] Table 4 provides a summary of current drinking water standard or guidance values for the Great Lakes states.

There are two important considerations when weighing action on drinking water standards. The first is whether the standard should take the form of an MCL or treatment technique. The second is identifying the PFASs to which the standard will apply. In a recent report, Natural Resources Defense Council recommended a combined approach: an MCL for particular PFASs, and a treatment technique for the total class of PFASs.[221]

States in the Great Lakes must move forward with establishing their own public drinking water standards. The standards should include not only MCLs or treatment techniques, but also an appropriate monitoring protocol.

GRANTS AND LOW INTEREST LOANS TO VULNERABLE COMMUNITIES

After states develop drinking water standards for PFASs, they should amend their revolving fund laws and policies to ensure a more equitable allocation of grants and low-interest loans to vulnerable communities.

The other major aspect of the Safe Drinking Water Act is the State Revolving Fund program (SRF).[222] The SRF's main objective is to get federal dollars to states so that states can help finance drinking water systems through grants and low-interest loans. Each state's revolving fund is comprised of the federal grant, a percentage of the federal grant that the state agrees to match, and revenue from loan repayment, among other things. Since the SRF's inception in 1996, Congress has contributed billions of dollars to state revolving funds. Based in part on an annual intended use plan that states submit to EPA, states are ultimately responsible for allocating loans and grants to water systems.

To address PFASs, many drinking water systems will incur costs. As described in the subsection above, many states are actively considering development of a drinking water standard for PFASs. Whether that standard takes the form of an MCL or treatment technique, the drinking water system will likely have to invest in monitoring and treatment. As with most increases to drinking water system costs, ratepayers will pay the bill through fees or taxes. Any increase in fees or taxes will have a disproportionate impact on vulnerable communities.

With regard to PFASs, states should make changes to their revolving fund program to assist drinking water systems that serve vulnerable communities. For drinking water issues other than PFASs, this assistance has taken many forms. For example, states can engage in principal forgiveness (like New York), or create a lower interest rate depending on the makeup of the community served by the system (like Illinois and Wisconsin), or get an extension on its loan term (like Michigan).[223] States should provide those kinds of assistance and others to drinking water systems affected by PFASs, but especially to systems that serve vulnerable and economically disadvantaged communities. State should demonstrate this by expressly changing applicable revolving fund laws and by delineating the actions they will take in their intended use plans.

A Note on No-Stricter-Than-Federal Laws

One needs to be aware of so called no-stricter-than-federal ("no stricter") laws. No stricter laws are state laws that limit that state's ability to enact rules that are more stringent than their federal counterparts.

No stricter laws come in various shapes and sizes. Sometimes, they target particular program areas. Other times, they create a sweeping limitation on any administrative action no matter the agency. In Wisconsin, the legislature requires that the Wisconsin Department of Natural Resources "comply with and not exceed the requirements of" the federal Clean Water Act.[224] In Michigan, the law imposes a higher standard on agencies that want to set any standard with regard to any regulatory framework that is more stringent then the federal counterpart.[225] In those instances, the agency must demonstrate a "clear and convincing need" to exceed the applicable federal standard.

There has never been an analysis of the actual impact of such laws. Environmental Law Institute conducted a helpful 50-state survey of these laws focusing on Clean Water Act implementation and enforcement.[226] However, that study provides more of a taxonomy of what exists as opposed to an analysis of how the laws actually impact standard setting.

It is worth accounting for these laws when deciding whether and how to persuade states to act on PFASs at a time when the federal government is just beginning to regulate PFASs in an enforceable manner. If no enforceable federal standard exists, the states with the no stricter laws have the opportunity to enact their own, protective standards. Urgent action can be advantageous, given the relatively slow movement on the issue at the federal level, backtracking that has occurred on other water policy issues, and the potential for less protective standards being promulgated.

TABLE 5. Great Lakes State Clearinghouses on PFASs

STATE	PROGRAM OR CLEARINGHOUSE/DESCRIPTION	CITATION
Illinois	None identified[a]	-
Indiana	None identified	-
Michigan	Michigan PFAS Action Response Team (MPART); Significant coverage of initiatives and information, including general summaries of sources, health and ecological concerns with PFASs, contaminated sites, PFAS foam, and testing and treatment approaches.	Michigan PFAS Action Response Team, 2019.[227]
Minnesota	Perfluorochemicals (PFCs), and Perfluoroalkyl Substances (PFAS); Significant coverage of initiatives and information between two agencies, including general information on PFASs, several reports (including related to settlement with 3M), identification of waste sites, summaries of sources, health concerns with PFASs, information on private well testing, point-of-use treatment, and other information.	Minnesota Pollution Control Agency, 2019 and Minnesota Department of Health, 2019.[228]
New York	Per- and Polyfluoroalkyl Substances (PFAS); General information (including fact sheets) on PFASs, the Water Quality Rapid Response Team (to test drinking water near sites with suspected PFAS use), information on firefighting foam collection, a statewide survey on PFAS use, and other information.	New York Department of Environmental Conservation, 2019.[229]
Ohio	None identified	-
Pennsylvania	PFAS: What They Are; general overview of PFASs, approach to response in the state, and information on sites under investigation, including more detailed information on two sites.	Pennsylvania Department of Environmental Protection, 2019.[230]
Wisconsin	Per- and polyfluoroalkyl substances (PFAS) contamination, and Per- and Polyfluoroalkyl Substances (PFAS); general information on laws and rules related to PFAS, a PFAS Technical Advisory Group, a link to information on contaminated sites, and brief information on exposures, health effects, and standards.	Wisconsin Department of Natural Resources, 2019 and Wisconsin Department of Health Services, 2019.[231]

a: Though not a formal state agency program, the Illinois Sustainable Technology Center briefly references PFASs in the context of chemicals of emerging concern.[232]

Great Lakes State PFAS Clearinghouses

The above sections reviewed state activities related to PFASs across a number of areas. Most Great Lakes states have developed programs and/or websites serving as clearinghouses for information on PFAS-related initiatives in their states, and those clearinghouses are summarized in Table 5. As noted in the table and summarized in sections above, several states have been active in addressing PFASs. Minnesota has been dealing with contaminated sites associated with PFAS manufacturing (at 3M facilities) for over 15 years, and has been involved in other initiatives, including in support of development of fish consumption advisories as previously noted. Efforts in Michigan have ramped up significantly in the past several years, including with establishment of the Michigan PFAS Action Response Team, and two other states (New York and Wisconsin) have established dedicated committees or work groups addressing some aspect of the PFAS problem. We did not find publicly available information on any statewide initiatives or state-supported clearinghouses on PFAS activities in Illinois, Indiana, or Ohio.

International Programs Affecting the Great Lakes Region

As stated at the start of the State Policy Tools to Address PFAS Impacts to Water Quality section on page 21, the emphasis on policy recommendations in this report is for U.S. states, which in many cases involves implementation of federal programs. However, because the Great Lakes are binational (with all lakes but Lake Michigan straddling the international border), it is important to note that there are a number of Canadian programs addressing PFASs as well, which are beyond the scope of this review. A brief discussion here addresses a binational agreement and international treaty, both relevant to PFASs in the Great Lakes region.

The Great Lakes Water Quality Agreement (GLWQA) was first signed by the U.S. and Canada ("the Parties") in 1972, and amended on several occasions, most recently in 2012.[233] In the current version of the Agreement, most work occurs through the ten annexes, which address different issue areas affecting the Great Lakes. Annex 3 addresses chemicals of mutual concern, toxic chemicals designated by the Parties, and for which binational strategies are developed and implemented to reduce the chemicals in the Great Lakes.[234] To date, eight individual chemicals or chemical groups have been designated, including PFOS, PFOA, and long-chain perfluorinated carboxylic acids.[235] A strategy for these PFASs should be released for public comment later in 2019.[236] Though the GLWQA and work through the annexes does not provide any additional regulatory authority to the federal or other government agencies, the process does facilitate more targeted work, development of coordinated programs, and some accountability (including as reviewed by the International Joint Commission (IJC)) in assessments of progress towards meeting objectives of the GLWQA, including for chemicals of mutual concern.[237]

Substantial international work to address PFASs and other organic pollutants is coordinated under the Stockholm Convention on Persistent Organic Pollutants, first adopted in 2001, and entering into force in 2004, following the signing by the 50th country.[238] Canada has signed and ratified the treaty, while the United States has signed but not yet ratified or otherwise acceded to the treaty, meaning it is a nonvoting observer at meetings. In 2009, the Conference of the Parties listed PFOS, its salts, and perfluoroalkyl sulfonyl fluoride in Annex B to the Convention, which requires Parties to take risk reduction actions to address the chemicals' production and use, though some exemptions are allowed for products/uses where alternatives are not readily available.[239] More recently, on May 3, 2019, Parties to the Convention agreed to add PFOA, its salts, and PFOA-related compounds to the list of restricted substances, requiring similar actions to phase out production and uses, though again, exemptions were granted, including for use in firefighting foam.[240]

Conclusions and Recommendations

As documented in this report, per- and polyfluoroalkyl substances are yet another group of chemical contaminants of concern in the Great Lakes region. While two of the most commonly used PFASs have been phased out in the United States, production still occurs elsewhere, and hundreds of other PFASs are still in use in the United States While PFASs have been found in environmental media in the Great Lakes region, including air, water, soil, sediments, and biota, there are still a number of questions concerning ongoing sources of PFASs in the region, including for less-studied compounds, and implications for environmental cycling and exposures.

In addition, there are multiple ecological and human health concerns with PFASs, and much of the concern stems from the inherent characteristics of many PFAS chemicals, including their persistence, bioaccumulative potential, and toxicity (as manifested in various health endpoints, both concerning wildlife and human health). Because of concerns with certain PFAS chemicals (especially long-chain), industry has shifted manufacturing and use to other PFAS chemicals (often short-chain), but many of these compounds possess the same concerning characteristics.[241] Furthermore, although some PFASs have less bioaccumulation potential, those same characteristics allow the chemicals to be transported more readily in groundwater, and exposures (including to humans) and potential effects can still occur.[242] In addition, recently published research on PFASs in precipitation and surface waters from the Canadian portions of the Great Lakes showed that while PFOS and PFOA concentrations generally declined from 2006—2018, concentrations of short-chain PFAS either did not change or increased over the period, and the similar levels for perfluorobutanoate (PFBA) between more developed and more pristine geographic areas suggested the importance of atmospheric transport distributing the chemical far from sources.[243]

The widespread distribution and human exposures to PFASs can have economic implications as well. A recent study from the Nordic Council estimated the socioeconomic costs of not taking more aggressive action to address PFAS contamination in Europe, and estimated total annual health-related costs in the European Economic Area due to current exposures to PFASs of at least 52 billion Euros ($58 billion).[244] We are not aware of a similar assessment in North America, but given widespread distribution of and exposures to PFASs and generally similar population numbers, it is possible that health-related costs are similarly substantial.

Given these multiple concerns, a number of scientists have recently called for more actions to address PFASs globally, most of which are relevant to the Great Lakes region. The recent Madrid Statement on PFAS[245], a consensus paper by international scientists outlining a roadmap to confront and solve the PFAS crisis, called for actions by a number of sectors, calling on industry to increase provision of standards, testing data, content data in products; increase development of non-fluorinated alternatives; and phase out PFAS use where other alternatives are available. The statement also called for a number of government actions, including regarding restrictions on use and labeling requirements for industry; testing and other requirements; and development of public product registries and annual reporting of production, importing, and exporting of PFASs.[246] The absence of these types of requirements and actions highlights a broader challenge that has been identified in dealing with PFASs and similar chemicals, whereby governance systems often privilege industry concerns of market entry and protection of trade secrets over public health protection.[247]

Based on the review in the first part of this report, key recommendations to improve scientific understanding of PFASs relevant to the Great Lakes and implementation of programs include the following, with many involving federal governments coordinating with states, the province of Ontario, local communities, academic researchers, NGOs, and industry:

- Develop comprehensive inventories of sources of PFASs in the region, ranging from manufacturing to use to disposal stage, and support PFAS listing and reporting via the U.S. Toxics Release Inventory.
- Carry out modeling and other work to identify PFASs of greatest potential human health and ecological concern, based on available (or predicted) information on persistence, bioaccumulation potential, and toxicity, as well as additional exposure information.
- Develop a better understanding of environmental cycling of PFASs in the region through consideration of information on sources, modeling and measurement assessments, potentially with a geographic focus (e.g., through a mass balance study).
- Develop a framework for identifying priority monitoring needs in the Great Lakes environment, expand monitoring (including for fish and wildlife) in a comprehensive but systematic manner, and include reporting as part of the State of the Great Lakes reports.

- Support studies (both laboratory and field) on potential PFAS impacts to wildlife in the region, including a broader suite of bird, reptile and amphibian, and mammalian species at risk.
- Increase understanding of human exposures and potential effects due to PFASs through support for laboratory animal and epidemiological studies, as well as broader but targeted biomonitoring, including considering susceptible populations.
- Support continued funding for monitoring and cleanup of contaminated sites (including Areas of Concern and other sites)
- Continue Great Lakes Restoration Initiative funding, while ensuring availability of funds for PFAS research from other federal programs.
- Initiate or expand, as appropriate, incorporation of PFASs into fish contaminant advisory programs, including considering implications of exposures to multiple PFASs as well as other contaminants.
- Support research into cost-effective approaches to reduce PFAS releases, including from wastewater treatment plants, and to control and adequately treat PFASs in drinking water.
- Explore broader approaches to addressing PFASs, including promoting research and development into other chemicals and/or processes that do not entail use of these inherently persistent chemicals.

Concerning policies and legal programs to address PFASs in the Great Lakes region, this assessment focused on efforts on the U.S. side, including work through several key federal statutes, where states have authority to implement programs. The Clean Water Act has the potential to address PFASs in a number of ways, including through ambient water quality standards, the point source permitting program, and in particular programs for wastewater treatment plants. Efforts through the Safe Drinking Water Act can also be fruitful, including around development of a national primary drinking water standard. Work through federal cleanup laws for contami-

Wastewater treatment plant in Ann Arbor, Mich. Public wastewater treatment plants and drinking water systems in the Great Lakes region were not designed to treat PFAS. Communities face expensive upgrades to deal with PFAS and other challenges. The federal government can help by investing in the nation's water infrastructure. Photo credit: Southeast Michigan Council of Governments.

nated sites is also necessary, as is work under several other statutes, including the principal federal law regulating production of chemicals such as PFASs in the first place. Recommendations across the various statutes are provided here.

Clean Water Act (both in general, and concerning wastewater treatment plants (or publicly-owned treatment works, POTWs)):

- States, through legislation or rulemaking, should develop numeric water quality criteria for PFASs of concern.
- States, through the permitting process, should include in National Pollutant Discharge Elimination System (NPDES) permits effluent limits and monitoring requirements for PFASs.
- In the absence of applicable effluent limitation guidelines, agencies must include technology-based effluent limits for PFASs in NPDES permits through the exercise of the permit writer's best professional judgment.
- Agencies must include water quality-based effluent limits for PFASs in NPDES permits based on narrative or numeric criteria and the overall need to ensure attainment with water quality standards.
- Agencies must include monitoring requirements where PFASs of concern are expected to be present in influent and not expected to be entirely addressed through the facility's treatment process.
- Through permitting, states should include in public wastewater treatment facility NPDES permits monitoring requirements.
- Wastewater treatment facilities, through legislation or rulemaking, should apply specific monitoring protocols and pretreatment standards to industrial users that are expected to discharge PFASs to the treatment facility.
- States must condition use of biosolids that may contain PFASs and require pollution control standards where necessary.

Cleanup laws (including the Comprehensive Environmental Response, Compensation and Liability Act):

- States should designate PFASs of concern as hazardous for purposes of their cleanup laws.
- States should develop enforceable cleanup criteria.

Safe Drinking Water Act:

- States through legislation or rulemaking should develop enforceable PFAS drinking water standards for public water systems.

States with "no-stricter-than-federal" laws:

- Given the slow progress on PFASs at the federal level in the U.S., even states with a "no-stricter-than-federal" law can take actions addressing PFASs ahead of federal requirements.

Binational/International Agreements:

- U.S. EPA and Environment and Climate Change Canada should adopt an aggressive binational strategy addressing multiple PFASs in the region, through Annex 3 of the Great Lakes Water Quality Agreement.
- Both Canada and the United States should implement policies consistent with requirements in the Stockholm Convention on Persistent Organic Pollutants (even though the United States has yet to ratify the treaty), including promoting international initiatives to reduce the global uses, trade, and releases of PFASs, including regarding PFAS-containing products.

In summary, there are a significant number of policy approaches that can be pursued to tackle the PFAS crisis in the Great Lakes region. This report has emphasized approaches states can take, including through programs under federal laws such as the Clean Water Act and Safe Drinking Water Act, and to a lesser extent cleanup programs. Though federal actions are needed as well, and there is currently significant Congressional activity on PFASs, there are a number of activities states can take to address PFASs, including with regard to improved monitoring, development of water quality standards, more restrictions on wastewater treatment plants (including stringent permits), resource support for public water systems, expansion of fish and game advisory programs, and further research across a number of areas, including with federal agencies, other states, academic groups, and others engaged on PFAS in the region. PFAS contamination in the Great Lakes region is a complex problem that will require sustained, comprehensive efforts to resolve.

It is imperative that Great Lakes states act with urgency and purpose to confront the PFAS crisis, in particular given uncertainties around legislation, and the general slow movement or even rollbacks to multiple environmental programs underway by the Administration.
For these reasons, states need to lead the charge in confronting the PFAS crisis to protect the drinking water, public health, economy, and fish and wildlife in the region. Delay will only make the problem worse and more costly to solve.

Appendix — Chemical Acronyms[a]

ACRONYM	FULL NAME[b]
PFASs	Per- and polyfluoroalkyl substances
PFCAs	Perfluoroalkyl carboxylic acids
PFSAs	Perfluoroalkyl sulfonic acids
PFECHS	Perfluoroethylcyclohexane sulfonic acid
PFHxS	Perfluorohexane sulfonic acid
PFMeCHS	Perfluoromethylcyclohexane sulfonic acid
PFOS	Perfluorooctane sulfonic acid
PFBA	Perfluorobutanoic acid
PFHpA	Perfluoroheptanoic acid
PFHxA	Perfluorohexanoic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid

a: This appendix lists the relatively small number of PFAS compounds discussed in this report. Note there are thousands of other PFAS compounds within the several broad classes, including non-polymeric perfluorinated compounds (such as PFOS and PFOA), polyfluorinated compounds, and the polymers.

b: It is common in the scientific literature concerning PFASs to use the same acronym when referencing the acid form of the compound as well as for the compound that has lost a hydrogen ion (i.e., the anionic form). For example, PFOS can refer to either perfluorooctane sulfonic acid or perfluorooctane sulfonate.

See additional discussion on PFAS nomenclature in reference 1 on next page.

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Unless indicated otherwise, Web sites are current as of early September, 2019.

1 Note that nominally, PFAS would be plural—i.e., encompassing per- and polyfluoroalkyl substances as a family (see Interstate Regulatory Technology Council, Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS), Nov. 2017). However, given the common use of "PFASs" in the scientific literature when referencing multiple compounds in the family (except when used as an adjective), we are adopting that convention here.

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In this June 6, 2018 photo, residents demand answers and solutions outside of Robert J. Parks Library, in a rally for safe water before a Restoration Advisory Board meeting in Oscoda, Mich. These residents are asking the Air Force to claim responsibility for damages after findings of high levels of the toxic chemical PFOS in the foam near a plume coming from the former nuclear bomber base. PFAS foam continues to rise up on the shoreline of Van Etten Lake almost daily, and residents are demanding answers and solutions.