NC STATE UNIVERSITY

September – October 2022

NC STATE ECONOMIST

The Economics of the Emerging PFAS Problem

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80 years ago, a new class of chemicals hit the market, led by brand names Teflon and Scotchgard. These per- and polyfluoroalkyl substances (PFAS) were widely adopted thanks to unique properties that proved beneficial in countless applications. Public concern with the use of PFAS has risen dramatically in recent years due to emerging scientific evidence about their ecotoxicity and links to human health. In North Carolina, these heightened concerns are centered around the Cape Fear River and several drinking water reservoirs where nearby wastewater plants, airports and factories have been releasing PFAS for decades.

In this edition of the NC State Economist, we discuss PFAS by examining their benefits and costs to society, evaluate the effectiveness of current regulations, and consider the future of PFAS use and mitigation in North Carolina.

Background

PFAS are known for their durability, resilience, and extremely low friction. They are ubiquitous where non-stick, stain-resistant, and waterproof properties are desirable. Consumer products typically made with PFAS include carpets, apparel, cosmetics, hair conditioners, food packaging, cookware, cleaners, surface treatments, medical and dental devices, and sports equipment. Industry use is widespread where extreme temperatures, harsh environments, or physical wear are expected.

While thousands of PFAS variants exist, most commercial use is accounted for by fewer than 300 compounds. Throughout the 20th century, these compounds were invented, produced, and disposed of directly into waterways or through wastewater treatment systems not designed to remove them. Military bases, landfills, and airports are other notable sources. Once in the environment, PFAS can reside in soil and water for decades until eaten or absorbed by microbiota and insects; these in turn are eaten by larger creatures and over time PFAS bioaccumulate up the food chain. This effect is so potent that PFAS are measurable in wild bald eagles and polar bears, and river fish can have tissue concentrations 10,000 times higher than surrounding waters.

In the late 1990s, two major PFAS (PFOA and PFOS) were found to have bioaccumulated in the general population. Soon after, domestic production of both was curtailed, but years later the chemicals continued to show up in most Americans' blood. A 2015 EPA survey of U.S. rivers, creeks, and Great Lakes found more than 99% of fish had detectable levels of PFOS, most so contaminated that a single fillet would exceed an adult's monthly safe consumption levels. The ability of PFAS to cycle through the food chain for decades without breaking down has led to its moniker as a "forever chemical."

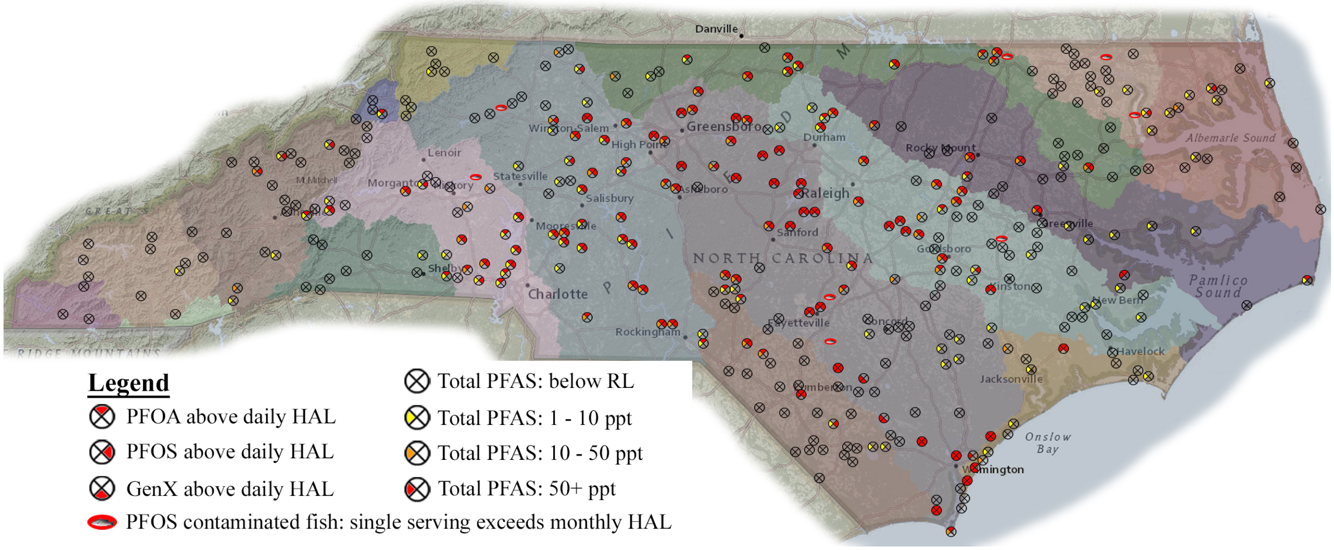

Figure 1: Distribution of PFAS in North Carolina's water supplies. Icons are based on latest EPA health advisory levels (HAL) for individual PFAS compounds (PFOS = 0.02 ppt, PFOA = 0.004 ppt, GenX = 10 ppt). Surface water sources were significantly more likely to exceed reporting and health advisory levels than drinking water sourced from groundwater aquifers. Fish fillets contained between 1 ppb to 11 ppb PFOS.

Watershed map courtesy of N.C. Environmental Education. Data courtesy of NC PFAS Testing Network and the EPA.

PFAS Exposure Routes

How do PFAS make their way into our bodies? For most Americans, food makes up 80% of total PFAS intake. Drinking water, dust inhalation, hand-to-mouth contact, and dermal exposure are other common pathways. Depending on a person's residence, age, and occupation, any pathway can be the dominant source. For infants, the prime exposure pathways are breast milk, dust inhalation, and hand-to-mouth contact.

Food:
According to the EPA, diet typically comprises most of our exposure to PFAS. Freshwater fish are often contaminated, especially bass, trout, and catfish. PFAS in water and soil contaminate root crops and to a lesser extent, vegetables and grains; leafy crops effectively concentrate short-chain PFAS. High levels are also found in eggs, milk, and meat. Stain-resistant containers, packaging (e.g. popcorn bags, muffin cups, or pizza box liners), and non-stick cookware can transfer PFAS onto food.

Water:
Based on 2022 EPA guidance, many municipal water supplies around the country dramatically exceed health advisory levels for PFOA (0.004 ppt) and PFOS (0.02 ppt); in North Carolina, nearly a third of water supplies fall into this category (Figure 1). In extreme cases, water can exceed advisory levels by a factor of a million and be the dominant exposure pathway. Aquifers and private wells are susceptible to PFAS contamination via percolation from surface waters, landfills, and

other point sources.

Inhalation:
Industrial workers, especially at waste processing facilities and certain factories, are susceptible to volatile PFAS and PFAS-laden particulates. PFAS-laden dust from carpets, toys, and clothing is found in many offices, homes, and schools, and in some cases is the most significant exposure route for children.

Skin and Hand-to-Mouth:
These routes are generally minor but can be significant for infants and adults who routinely handle PFAS-containing products.

Societal Benefits of PFAS

PFAS contribute economic value through their use in goods and processes, serving as end materials, additives, coatings, lubricants, and manufacturing aids.

Approximately 100,000 tons of PFAS are made or imported annually, with manufacturer and distributor revenues reaching billions of dollars. Downstream economic benefits are even larger. The $210 billion American semiconductor industry is heavily reliant on PFAS for materials and manufacturing processes. For other industries, PFAS increase efficiency, generating savings ranging from millions to billions of dollars. For consumer goods, PFAS can also expand the functionality and quality of products that firms produce; these benefits are passed on to consumers through greater choice and lower prices.

To date, no comprehensive study has calculated the total social benefit of PFAS. To accomplish this would require evaluating each PFAS use and then determining the value forgone from a transition to a PFAS-free alternative. For example, PFAS-free rain jackets have similar functionality and price to PFAS-coated jackets, so the added value of PFAS is low. With semiconductor manufacturing, the properties of PFAS acids and polymers are critical to the production of modern computer chips, and thus provide large societal benefits.

Health and Economic Costs of PFAS

At all stages of life, PFAS enter our bodies and accumulate in our tissues and organs, and for pregnant women, in the fetus. Animal studies confirm that PFAS exposure routes and dosages are the primary determinants of negative health outcomes, yet are difficult to track in people. Despite lacking causal links, a 2019 federal review found significant correlations between exposure to long-chain PFAS (more than eight carbon atoms) and multiple health issues: liver disorder, high cholesterol, altered metabolism, hypertension, pre-eclampsia, decreased antibody response to vaccines, fertility issues, decreased birthweight, reduced immune system function, increases in disease-specific mortality, increased respiratory illness, increased cardiovascular disease, and colon polyps.

Mirroring recent trends in manufacturing, health research has shifted focus to short-chain PFAS (less than eight carbon atoms). In some cases, short-chain PFAS are just as robust and persistent as their long-chain analogs, have identical cell toxicity, and are more biologically mobile. In one extreme case, a short-chain PFAS called GenX is 10 times as toxic as PFOA, the long-chain compound it replaced. GenX is manufactured in North Carolina by a facility that discharges its wastewater into the Cape Fear

River. Suspected downstream effects include a thyroid cancer cluster and alligator populations with autoimmune disorders.

One influential report from the European Union calculated direct healthcare costs of ongoing (unmitigated) exposure to PFAS surfactants on the order of $54 billion to $82 billion per year. Adjusting for differences in population, this translates into approximately $37 billion to $59 billion per year in the U.S. This cost is not evenly distributed across the population and fails to capture quality-of-life reductions from illness or lost productivity due to early death and caretaking responsibilities. Considerable uncertainty remains regarding the onset and magnitude of negative health effects due to PFAS exposure, and given the potential for significant and costly diseases, affected populations may be willing to pay to avoid these risks.

Current State of PFAS Regulation

The 1976 Toxic Substances Control Act and its 2016 amendment are the primary legislation governing PFAS. These laws give the EPA 90 days to decide on toxicity and restrictions regarding the use or disposal of any novel chemical. This short window implies that in most cases, the EPA's determination must be made without the benefit of longitudinal data on biodegradability, environmental fate, human toxicity, or ecotoxicity. Given the myriad ways PFAS can affect the human body and the suspected time lag between exposures and illness, this approach likely misses important long-run impacts.

To date, only a handful of PFAS (including PFOS and PFOA) are limited in use or disposal by federal regulation. Seven states regulate public water utilities via enforceable standards for specific compounds, however these standards all exceed the EPA's latest health advisory levels for PFOS, PFOA, and GenX.[1] More states have guidance or notification standards in place, but these are not enforceable. One potential regulatory solution is to create contaminant limits based on cumulative exposure to all PFAS, as research shows these joint limits do better at protecting human health. Similarly, some experts recommend the use of a class-based regulatory approach, as has been done for polychlorinated biphenyls (PCBs) and chlorofluorocarbons (CFCs).

PFAS Monitoring and Remediation

In 2013, nationwide testing of large water utilities formed the basis for increased federal attention on PFAS as emerging contaminants. Some states, including North Carolina, currently fund ongoing water utility and well testing. This monitoring is effective but limited: PFAS tests require specialized analysis equipment that prohibits continuous monitoring, generally cannot detect very low concentrations, and only exist for a subset of the chemicals. As such, individual exposure is likely higher than documented.

When PFAS are detected, communities need to evaluate the benefits and costs of removing them from the environmental cycle. With current technology, the primary locations for PFAS capture are drinking water supplies and factory discharges. As PFAS resist biological, chemical and thermal destruction and can remain toxic for centuries, end-of-life disposal choices are critical to prevent recontamination.

Water utilities are readymade candidates for removing PFAS, but doing so may be prohibitively expensive. The best practical technology (granular activated carbon) has high operating costs, and the best available technology (reverse osmosis) has even higher costs and is also energy and water

1 States with enforceable Maximum Contaminant Level (MCL) standards: MA, MI, NH, NJ, NY, VT, and ME. North Carolina is developing a MCL standard and currently has a non-enforceable guidance standard.

intensive. Both system types are also used for private wells and point-of-use filtration.

As industry is often the primary source of PFAS emissions, end-of-pipe technologies can capture discharges before they are emitted into the environment. Such treatment at the source has the benefit of lowering downstream human and wildlife exposure as well as utility treatment costs. The costs to industry of adopting these filtration technologies are difficult to estimate, although targeted filtration of PFAS is likely more cost effective than general filtration methods. Moreover, closed-loop water systems, where appropriate, could eliminate PFAS discharge entirely.

Biosolids management offers another potential solution. In the U.S., biosolids are sold by wastewater treatment plants for soil amendment, and these can contain very high levels of PFAS. Current EPA rules do not require testing biosolids for PFAS, allowing these pollutants to shortcut back into food supplies and surface water. Segregating contaminated biosolids for use in specific applications and locations can slow the cycle.

Of the remediation options, most efforts to date have focused on water supply treatment. The country uses approximately 26.6 billion gallons per day for domestic water use, of which 88% is sourced from public utilities and the remainder from private wells. If we extrapolate from recent municipal projects to estimate added costs for all public water utilities, we find that treatment will likely be around $2 billion to $10 billion annually. Large systems using granular activated carbon would have relatively lower treatment costs, with increasing costs for smaller systems and reverse osmosis technology. Infrastructure expenses to add this filtration capability are uncertain; retrofits and new treatment plants could cost hundreds of billions of dollars nationwide, depending on the technology selected and current state of each utility.

Conclusion

For decades PFAS were generally viewed as harmless, and there was no economic incentive for firms to develop alternatives or take precautions with their disposal. Over time, these chemicals became integral to many products and industries, resulting in higher quality and lower cost products. Emerging evidence suggests the serious health consequences of PFAS contamination, but the effects are uncertain and their full costs unquantified.

While research continues, federal and state governments have moved forward with risk-management efforts. In North Carolina, the Department of Environmental Quality (DEQ) continues with public and private water system testing to monitor PFAS exposure levels. The state is developing regulatory standards for ground, surface, and drinking water to ensure that PFAS target limits meet scientifically based safe dose values, while also encouraging firms and municipalities to voluntarily monitor, disclose, and reduce PFAS discharges. Finally, DEQ aims to protect public health by cleaning up PFAS-contaminated sites.

North Carolina communities are also moving ahead with individual mitigation measures. The Town of Pittsboro recently upgraded its water treatment plant with granular activated carbon filtration, while Brunswick County is adding a reverse osmosis system to manage water sourced from the Cape Fear River. The state is also on track to disburse federal grants from the bipartisan Infrastructure Investment and Jobs Act of 2021, which dedicates $50 billion to water and wastewater-related investments and prioritizes addressing PFAS contamination.

PFAS contamination is a significant challenge without clear solutions. A deeper understanding of the benefits of these chemicals, their health effects, and their mitigation costs, will allow North Carolina communities and policymakers to make socially beneficial decisions regarding PFAS use, regulation, and remediation.

Additional Reading

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3. Toxicological Profile for Perfluoroalkyls. (2021). US Department of Health and Human Services. https://www.atsdr.cdc.gov/toxprofiles/tp200.pdf

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