Scientific Support for Regulation of PFAS and 1,4-Dioxane

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Contents

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1. Introduction

Environmental regulations are designed to protect public health from hazardous chemicals produced by industry, but it is known in the scientific and regulatory community that all potential contaminants are not successfully limited under current environmental regulations [1]. Dangerous chemicals may be under- or unregulated for several reasons, including:

- It is challenging to test for the chemical
- It is challenging or expensive to remove the chemical from the environment
- There is insufficient research describing human health hazards
- New hazardous chemicals are introduced in response to bans
- There are limited regulatory resources to enforce and monitor restrictions.

Incorporating scientific knowledge into regulations is critical for limiting dangerous contaminants and protecting public health. Per- and polyfluoroalkyl substances (PFAS) and 1,4-dioxane are among these widely researched but under- or unregulated contaminants that can have serious impacts on human health.

PFAS and 1,4-dioxane are widely researched but under- or unregulated

This document provides an overview of current research on PFAS and 1,4-dioxane for interested advocates. We describe what is known about the extent and transport of these chemicals, and we identify promising treatments and regulations that may better protect the public. We also include a more detailed account of research in the Southeastern U.S. for the benefit of advocates in this region. The overall goal of this review is not to be comprehensive but instead to highlight pertinent trends in recent research.

2. PFAS and 1,4-dioxane are all around us

PFAS are a group containing over 3000 synthetic chemicals that have been manufactured since the 1930s [2]. This group includes widely researched substances such as PFOA, PFOS, and GenX as well as thousands of under-studied but potentially harmful varieties [3]. PFAS repel both water and fats making them useful in many household applications including nonstick cookware, electronics, food packaging, stain resistant fabrics and carpets, paints, adhesives, personal care products and also composite woods and firefighting foams [4]. When known PFAS are banned, slightly altered PFAS may be developed to fulfill industry needs [5]. Each year, dozens of new PFAS chemicals are identified, each of which may have slightly different levels of toxicity and response to removal methods.

Many PFAS persist in the environment where they can have dangerous impacts on human health. The diversity and sheer number of PFAS species makes it challenging to successfully measure the extent of the problem [6], though it is known that PFAS are ubiquitous in water around the globe [7]. Elevated concentrations of PFAS have been reported near industrial sites, military fire training areas, airports, and wastewater treatment plants [8].

1,4-Dioxane, commonly known as dioxane, is also a human-made chemical that can be found in water sources around the world [9]. 1,4-Dioxane is used during the production of cosmetics, detergents, and shampoos.[1] It became a popular component in chemical manufacturing in the 1940s and was recognized as a human carcinogen and water contaminant in 1978 [10]. Like PFAS, traditional treatment methods do not remove 1,4-dioxane from drinking or wastewater. Its rapid movement through the environment and resistance to treatment makes regulating it difficult.

3. Once produced, PFAS and 1,4-dioxane pose persistent problems in the environment

PFAS are found in water and food

Once products containing PFAS have been created, water used during manufacturing may be released to wastewater treatment facilities [11] or directly into streams [12]. The structure of PFAS molecules make them easily dissolvable in water [13] and can take 1 to 3 years to degrade [14]. The rates of degradation among PFAS are highly variable and site-specific [15].

Traditional treatment methods fail to remove PFAS from wastewater and solid waste. Wastewater contaminated with PFAS may eventually be used to irrigate crops [16, 17, 18, 19] or may contaminate fish living in downstream waterbodies [20]. Contaminated solid waste may be applied to agricultural fields as a fertilizer [14, 6, 21, 22] or enter the environment through disposal into landfills. PFAS entering landfills lacking a sufficient lining can lead to groundwater contamination [23].

PFAS are also transported through the air [6]. Atmospheric transport and subsequent deposition results in measurable PFAS accumulation far from their point of production and have even been detected in the blood of polar bears [4]. Though production of certain PFAS has decreased since 2000, it can still be detected in aquatic and terrestrial ecosystems across the US, especially in animals that are higher in the food chain [24].

A study of PFAS blood concentrations in people in urban areas across the US showed that concentrations decreased between 2000 and 2015, but were still detectable. This was likely due to a combination of regulations limiting PFAS production in industry [25], and voluntary reduction of PFAS production guided by the U.S. Environmental Protection Agency (US EPA) [24], but the risk to new PFAS species still remains.

1,4-Dioxane is in water, but chemical transport is not fully understood

1,4-Dioxane can rapidly move through the soil and in to groundwater, where it persists for years [26, 27, 28]. It also readily evaporates and can be found as an air contaminant far from sources of origin [24, 29]. It persists longer in surface waters and groundwater than in air, and lasts from days to years in groundwater depending on local soil and climate types [27].

Almost 30 million Americans are exposed to 1,4-dioxane through drinking water

Though the sources and transport of 1,4-dioxane are more poorly understood than for PFAS, about 1 in 5 drinking water plants in the United States have been shown to contain 1,4-dioxane levels above the minimum risk level. Almost 30 million Americans are exposed to 1,4-dioxane through drinking water with levels above the health-based reference concentration

[1] https://www.atsdr.cdc.gov/phs/phs.asp?id=953&tid=199

of 0.35 µg/L [9].[2] 1,4-Dioxane occurrence is more common in drinking water of highly populated and industrial regions of the US and larger public water systems [9].

Areas with historical contamination from industry may be at increased risk of 1,4-Dioxane contamination. Methods testing for 1,4-dioxane were not widely available before the 1990s, so regulated hazardous site clean-ups initiated before then did not test for this contaminant. Therefore, many currently approved remediation plans are likely not addressing 1,4-dioxane sufficiently [10]. One promising way to find 1,4-dioxane pollution is to test areas contaminated with chemicals that are known to occur alongside it. In particular, 1,4-dioxane is frequently used as a stabilizer for other regulated compounds including 1,1,1-trichloroethane (TCA) or trichloroethylene (TCE). This means that areas that have historically been treated for TCE and TCA may also be contaminated by 1,4-dioxane. A study conducted by the U.S. Air Force found that 17% of groundwater wells contaminated with TCA and/or TCE also contained 1,4-dioxane, and nearly all 1,4-dioxane contamination co-occurred with TCA and TCE [30]. Current and historical clean-up efforts for TCA and TCE should be re-examined for 1,4-dioxane contamination [31].

4. PFAS and 1,4-dioxane exposure pose health risks

PFAS have been linked to cancers and diabetes

PFAS with physically larger molecules ("long-chain PFAS," including PFOA and PFOS) are more likely to accumulate in tissues, and are therefore more dangerous [32]. Humans may be exposed to PFAS through use of consumer products, consumption of water contaminated by industrial sources or landfills, or through consumption of food contaminated through treated waste or irrigation water. Some studies suggest that PFAS are within detectable levels in nearly every person's blood [4].

PFAS are within detectable levels in nearly every person's blood

Early studies of PFAS conducted by industry tested exposure in animals to better understand the effects in humans. These found that PFAS compromised the immune systems of monkeys, and strongly suppressed the immune systems of rodents [33]. At high doses, ingestion of PFAS even led to mortality [33, 34].

Impacts of exposure to PFAS is complex in humans, but is particularly harmful during early stages of development. Babies are exposed to PFAS umbilically during pregnancy, which can lead to low infant birth weights. They can also be exposed through contaminated breast milk [35, 36]. One study found that the duration of breastfeeding is closely associated with PFAS levels in children, with higher levels reported in children who breastfeed for longer [37]. The effects of PFAS exposure during early-stages of childhood development can also impact immune system response. One study examining this effect in infants and children found a clear decrease in antibody formation to tetanus that was strongly associated with PFAS exposure [37], suggesting weakened responses of the immune system.

The removal of PFAS from the body is linked to kidney function [38, 39], which varies with age, putting children and seniors most at risk of PFAS accumulation and higher blood concentrations. In a large-scale study of US women between 1995 and 2011, they found high blood concentrations of PFOS and PFOA, two common PFAS species, were associated with a higher occurrence of type 2 diabetes [40]. PFAS are also associated with disruption of thyroid hormones which can lead to cancer [41, 42, 43].

1,4-Dioxane is associated with cancer but this effect is poorly understood

1,4-Dioxane exposure also has negative health consequences, but less is known about its impacts on human health. Several studies of inhalation and ingestion of 1,4-dioxane exposure in mice show an impact on liver and nasal function [c.f. Table 2, ref. 29, 44, 45, 46]. Prolonged exposure in mice led to increased liver weight and eventually tumor formation [47, 45]. **The link between exposure and cancer has been shown in mice, but the carcinogenic effects due to 1,4-dioxane exposure has not been fully explored in people and more research is required** [29].

Humans can be exposed to 1,4-dioxane through contaminated drinking water or through air pollution, and women may have greater health consequences from exposure. Neither drinking water nor air is routinely monitored for 1,4-dioxane making it difficult to estimate the current exposure levels of the general population [47]. In general, more research is needed to understand the extent and effects of 1,4-dioxane exposure in people and the mechanisms by which it is toxic and carcinogenic. [29].

[2] µg/L is equivalent to parts per billion.

5. Environmental treatment options are promising but have limitations

Proper removal and treatment of emerging contaminants from lakes, rivers, and groundwater sources is critical for improving public health, especially as many parts of the world consider technologies for potable reuse of wastewater to adapt to water shortages. If specialized treatment methods are not implemented, contaminants including PFAS and 1,4-dioxane will become concentrated in this reused water [10]. Generally speaking, **there are promising treatment options for both PFAS and 1,4-dioxane, but their effectiveness of removal requires assessment at larger scales.** This section is an overview of those specific treatment options.

How does water treatment work?

Some water treatment techniques destroy pollutants completely, while others physically collect or concentrate the pollutants for safe disposal. Destroying pollutants generally means degrading (often through "oxidizing") a chemical through plant, bacterial, or fungal digestion, or by adding a chemical reactant. Methods that destroy pollutants require careful chemical analysis so that no dangerous intermediary products are created during degradation. Since environmental and wastewater treatment is primarily focused on treating large quantities of water (i.e. millions of gallons per day), the efficiency and cost-effectiveness of treatment is a major consideration when selecting the best methods. Importantly, no single treatment technique is likely to be the best choice for every remediation project, and multiple treatment techniques are usually combined in sequence to remove most contaminants.

PFAS treatment

PFAS are difficult to treat due to physical and chemical properties that make them highly soluble, leading to easy contamination and dispersal in groundwater. Conventional approaches for treating pollutants, including air stripping, thermal treatment, soil vapor extraction, and chemical oxidation, are ineffective with PFAS [13]. Emerging technologies for treatment are being developed and assessed. Below we highlight promising treatments for PFAS (adapted from [13, 48, 32, 49]):

- **Adsorption and binding PFAS to other materials:** Removing PFAS using ash or carbon (through "adsorption") is a promising low-cost technology with a high capacity to bind to PFAS. PFAS will bind to activated carbon which can then be collected and destroyed. This has been an accepted treatment for PFAS contamination since 2017 and has an efficiency greater than 90%. Another promising adsorption treatment uses organic silica which can bind and remove both short and long chain PFAS [48]. Safe disposal or cleaning of contaminated material is a concern for all of these options.
- **Concentrating PFAS for further treatment:** "Ozofractionation" is a commercially available process that uses ozone gas to bubble through contaminated water and collect PFAS as it passes through. Based on the chemistry of the interaction it can collect both short and long chain PFAS, but the concentrated PFAS then requires further treatment or disposal.
- **Filtration and reverse osmosis techniques:** Nanofiltration and reverse osmosis are being developed to filter PFAS from groundwater. Removal through reverse osmosis and filtration was higher than 99% and 90%, respectively.
- **Soundwaves or electricity to destroy PFAS ("sonochemical" or "electrochemical" destruction):** Using acoustics to create chemical reactions can destroy some PFAS but often fails to completely destroy the whole molecule. Electrochemical destruction is especially promising but can create toxic by-products when there are other contaminants in the water. These methods are not currently practical at large scales.
- **Removal through microbes and fungi:** Microbial degradation can be difficult because it requires specific environmental conditions for microbes to degrade PFAS. Also, there is very little understood about the potential byproducts. Fungi can degrade long-chain PFAS into less harmful short-chain PFAS.
- **Using chemical additives (Advanced Oxidation Processes, AOPs):** PFAS can be degraded or oxidized into shorter chain PFAS by adding chemicals that react with PFAS, but it does not completely remove the contaminants. The technical term for this type of treatment is "Advanced Oxidation Processes" or AOPs. The chemical reactions required to degrade PFAS have shown promise in lab-scale studies, but implementation at larger scales has not been thoroughly explored and could potentially form harmful byproducts.

Large-scale studies that test the treatments in the environment need to be conducted

1,4-Dioxane treatment

1,4-Dioxane is not removed by methods frequently applied for similar types of pollutants (i.e. chlorinated solvents). Like PFAS, well-established water treatment options including airstripping, thermal desorption, soil vapor extraction, and boiling water are ineffective methods for removing 1,4-dioxane [50, 31]. A recent study of groundwater in California suggested that concentrations of 1,4-dioxane can reduce naturally over time under certain circumstances, reducing concentrations by half every 2-5 years [27]. However, this does not address the urgent issue of removing the contaminant from drinking water.

Promising proactive treatment methods for 1,4-dioxane exist, but many of these have only been demonstrated in a laboratory setting [31]. This means that more **large-scale studies that test the treatments in the environment need to be conducted** before we understand how environmental factors, such as geology, climate, and other chemicals in the water, impact treatment effectiveness. The effectiveness of point-of-use treatment options (such as refrigerator or pitcher filters) varies greatly, and removal rates have been shown to range from 17% to >99%, depending largely on the age of the filter [51]. Furthermore, the removal of 1,4-dioxane can vary depending on the initial concentration, making it especially challenging to recommend consistent treatment options [51]. A summary of treatments tested in laboratory settings is provided below (adapted from [31]):

- **Absorbing or binding 1,4-dioxane to other materials:** Newly developed activated carbon materials, including Ambersorb™ 560, have shown high removal efficiency for 1,4-dioxane in both surface and groundwater. Disposing of the removed 1,4-dioxane presents challenges for this treatment option.
- **Removal through plants:** Hybrid poplars have been shown to remove 54% (+/- 19%) of 1,4-dioxane from groundwater in 9 days [52], which could prove to be a successful low-cost solution for groundwater contamination. Removal using other plant species has not been fully explored.
- **Removal through microbes:** Studies over the past 10 years have shown that 1,4-dioxane can be consumed by certain microbes in oxygen-containing (aerobic) environments. It can be challenging to maintain these microbes outside of laboratories. It may be possible to contain microbes in a gel that can be reused in 1,4-dioxane treatment, but more research is needed [53].
- **Using chemical additives (Advanced Oxidation Processes, AOPs):** Chemical additives can break down 1,4-dioxane to a point that traditional wastewater treatment processes can remove them. The additives required are different than for PFAS removal. AOPs present engineering challenges, especially for long-term ongoing treatment, and require costly technology or chemical additives. In laboratory experiments using AOPs on soil samples from a US EPA Superfund Site in Simpsonville, South Carolina, 1,4-dioxane concentrations were reduced by almost half [54].

6. Current US regulations are limited

PFAS regulations

Many major U.S. manufacturers[3] voluntarily phased out the use of PFOA between 2002 and 2015 through the US EPA PFOA Stewardship Program[4]. Despite this program, PFOA and other PFAS are still present in water supplies and new species are still being developed [5]. Concentration of PFAS in drinking water is still unregulated in most states (Figure 1) and most states with regulations only limit specific PFAS species in drinking water (such as PFOA or PFOS).

State and federal regulations for PFAS can be outpaced by the development of new species of emerging contaminants. For example, although PFOS and PFOA have been eliminated from major manuafacturing operations in North Carolina, 39 new and unidentified PFAS species have been detected below a manufacturing plant [5]. Also, many of these new regulations do not address treatment of contaminated sites. Despite reduced production of PFAS and 1,4-dioxane, they continue to be detected in plants and animals [24].

1,4-Dioxane regulations

While the World Health Organization, European Union, and Canada have determined a threshold for 1,4-dioxane concentrations in drinking water that leads to adverse health effects including cancer, there exists no similar threshold set by the US EPA [50].

Toxicologists agree that 1,4-dioxane should have a regulatory threshold, but there is disagreement about what this level should be [10]. Generally, the threshold for acceptable levels in water lowers with more 1,4-dioxane related research [31]. In the US, drinking water standards vary by state, but not all states have established limits (Figure 1). Colorado was the first to establish an enforceable standard for 1,4-dioxane in groundwater and surface water in 2004 [55]. Since, several US states have implemented similar 1,4-dioxane standards though only as nonenforceable guidance levels for drinking water, with New Hampshire having the most stringent at 0.25μg/L [9].

[3] Arkema, Asahi, BASF Corporation (successor to Ciba), Clariant, Daikin, 3M/Dyneon, DuPont, and Solvay Solexis

[4] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

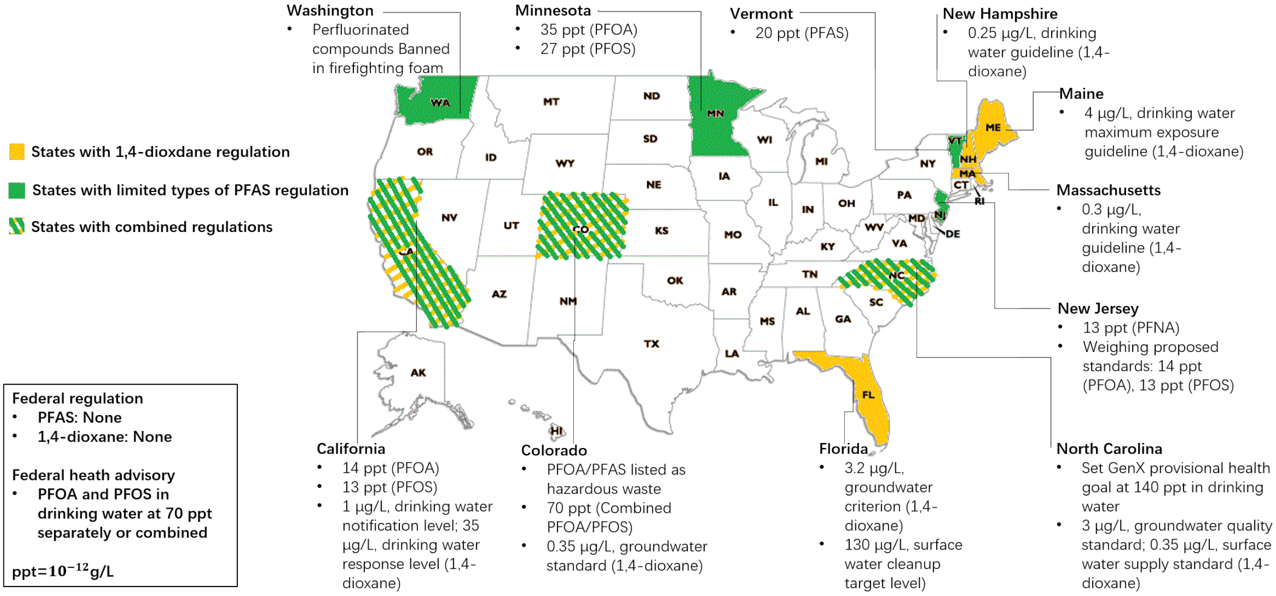

Figure 1: *Current PFAS and 1,4-dioxane regulation by US state (adapted from Bloomberg Environment[5]).*

7. PFAS and 1,4-Dioxane contamination in the Southeastern US

Advocating for state-level regulations can be improved through knowledge of research specific to the region. For this reason, we have included this section to highlight research about PFAS and 1,4-dioxane in the Southeastern U.S. Much of the research from this region reveals contamination from industry that has lead to exposure in wildlife or people. As discussed in the previous sections, exposure to these contaminants varies but it is often associated with contaminated drinking water. Figure 2 summarizes the concentrations of 1,4-dioxane measured in public water systems (PWSs) across the Southeast that serve more than 10,000 people based on the US EPA's nationwide Unregulated Contaminant Monitoring Rule data [56]. In this region, North Carolina had the greatest number of samples above the minimum reporting level (MRL) followed by Alabama and South Carolina. However, the number of samples above MRL in South Carolina comprised more than 35% of the total number of samples, whereas it comprised only 18.6% and 17.3% in Alabama and North Carolina, respectively. It is important to note that UCMR figures do not represent total exposure because they do not capture contamination of smaller and private water supply systems.

Six species of PFAS were also tested in the UCMR, with less than 2% of samples above the MRL in each southeastern state. This low occurrence may be due, in part, to testing for just six PFAS types.[6]

Emerging Contaminant Studies by State

Alabama

- **Decatur, AL**: Several studies have focused on the Tennessee River near Decatur. This area is close to several industrial facilities. In particular, carpet manufacturers in Dalton, Georgia have been accused of contaminating sites downstream, including in Decatur. In 2010, Washington et al. [14] showed that agricultural fields were contaminated with PFAS through the application of treated human waste. Newton et al. [57] found high concentrations of certain PFAS in streams and sediment, and that concentrations were greater downstream of manufacturing facilities. A third study found elevated concentrations of PFAS in blood and urine samples from local Decatur residents. These concentrations decreased by about 50% between 2010 and 2016 for most PFAS they tested. Exposure was highly associated with contaminated drinking water [11].

Georgia

- **Dalton, GA:** As of 2009, 90% of the world's carpet was produced in the Dalton area in northwestern Georgia. This industry uses PFAS, and in 2009 Dalton Utilities reported to the US EPA that large

[5] https://news.bloombergenvironment.com/environment-and-energy/glass-half-full-on-state-solutions-to-chemicals-in-water-corrected

[6] As noted in the introduction, the inherent challenge of measuring all types of PFAS is an ongoing limitation in any PFAS research that may bias results to show lower concentrations.

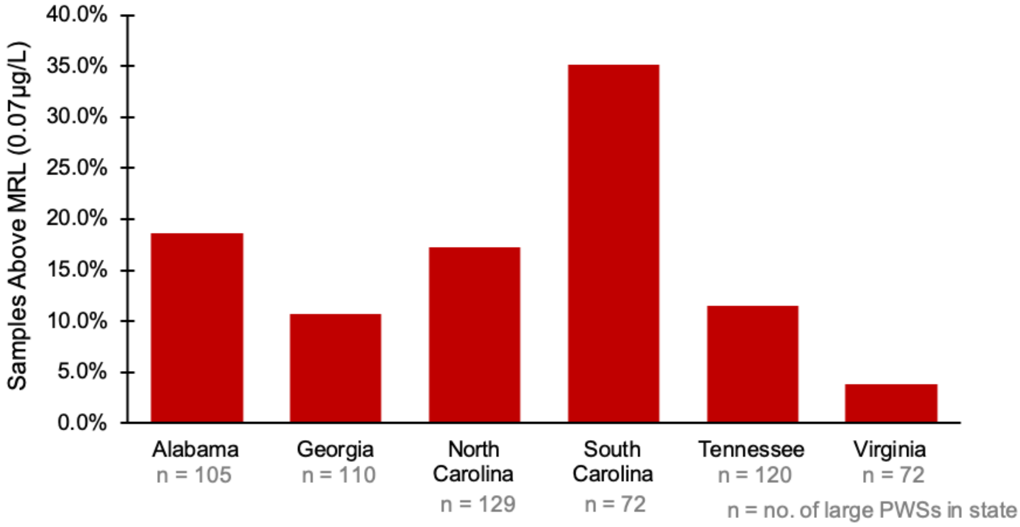

Figure 2: *The U.S. Environmental Protection Agency (US EPA) tested for 1,4-dioxane in public water systems (PWSs) serving a population of 10,000 or more between January 2013 and December 2015. Data summarized here includes the minimum reporting level (MRL[7]) in PWSs throughout the US Southeast. (Source: US EPA. The third unregulated contaminant monitoring rule (UCMR 3), 2016 [56]).*

amounts of PFAS were present in the treated waste and wastewater. This treated solid waste had been distributed for use as compost to the general public, and treated water was applied to land in the 9600 acre land application site owned by Dalton utilities. Konwick et al. (2008, [58]) found that concentrations downstream from this site exceeded safety thresholds for fish and birds.

- **Coosa River Basin, GA:** A 2011 study associated elevated PFAS concentrations in the Coosa River basin in Georgia with land application of treated waste from the Dalton municipal waste treatment facility [59]. In the same study, samples from the Conasuga and Oostanaula rivers were also found to be elevated well above US EPA health advisory levels at sites directly downstream from the manufacturers.

North Carolina

- **Statewide:** Data collected between 2013 and 2015 revealed that seven of the twenty highest concentrations of 1,4-dioxane in US drinking water occurred in North Carolina ([56] as cited in [51]). Von Ehrenstein et al. [36] found that living in North Carolina for 10 years or longer was related to elevated PFAS concentration in bodily fluids, though this study sample size was too small (34 individuals) to provide definitive evidence.
- **Cape Fear River Basin, NC:** In 2016, PFAS were found at higher levels than the US EPA lifetime health advisory level in 57 out of 127 sites sampled in the North Carolina Cape Fear River Basin [22]. A 2019 study by McCord et al. [5] posits that industrial entities in this river basin have created new PFAS in response to regulations. In this research, they identify 37 unregulated PFAS with chemistry slightly altered from banned species just downstream of manufacturing facilities. In some cases, new PFAS in the Cape Fear Basin are even less suitable for treatment than banned versions [22]. Treated wastewater from one North Carolina community in this area contained 154-1400g/L 1,4-dioxane and contributed to elevated 1,4-dioxane concentrations at downstream drinking water providers serving 1 million North Carolinians [9].

Industries in Georgia, North Carolina, and South Carolina have created hotspots for PFAS

- **Charlotte, NC:** Higher concentration of PFAS in blood plasma of donors in Charlotte, North Carolina is suspected to be due to exposure from the historic textile industry in Southwestern, NC. Overall, concentrations of known PFAS declined between 2000 and 2015 [25].

South Carolina

- **Statewide:** 55% of drinking water plants in South Carolina detected 1,4-dioxane, with 35% over the minimum risk level [60].

[7]The Agency for Toxic Substances & Disease Registry (ATSDR) uses the term “MRL” to describe “Minimal Risk Levels”. According to the UCMR-3, these two terms have no relationship to each other.

- **Charleston, SC:** Several studies in and around Charleston and Charleston Harbor have found PFAS. A 2015 study found that levels of PFAS in sediment in Charleston, South Carolina are higher than those reported in any other urban area in the United States [61]. Levels of PFAS measured in the plasma of dolphins near Charleston are assumed to be similar to that of regularly exposed humans (for example, people who work with PFAS). Higher levels of specific PFAS are detected in dolphins in areas with greater developed land use [61]. A 2019 study found that levels of PFAS in fish from the Charleston Harbor exceeded wildlife protection guidelines in 83% of fish tested [62].
- **Coastal SC:** Concentrations of PFOS in the blood serum of Gullah African Americans living in South Carolina decreased between 2003 and 2013, but concentrations of other types of PFAS remained stable. The concentration varied greatly depending on the age and gender (with older men at higher risk). The decline in PFOS is likely due to phasing out of these chemicals [63].
- **Multiple Wildlife Preserves:** A study of alligators' from 12 sites in Florida and South Carolina showed that all 125 blood samples contained at least 6 PFAS [64].

Tennessee

- **Cleveland, TN:** In recently released study, high levels of PFAS were found in foods distributed across the Southeast in 2001.[8] This included milk distributed to Cleveland, TN with measured concentrations of 0.573 ppm.[9]

Virginia

- No Virginia-specific studies were identified for PFAS or 1,4-dioxane.

8. Conclusion and recommendations

PFAS and 1,4-dioxane are ubiquitous in our everyday lives but their pervasiveness makes them difficult to trace to their sources and to treat in water. The potential health impacts associated with these compounds are widely recognized, even if the precise mechanisms for harm are poorly understood. So far, regulations in the United States have failed to adequately address these risks. Development of methods for testing and assessing the toxicity of PFAS, in particular, is challenging. There are thousands of types of PFAS in existence and more being created, making it difficult to identify the extent of contamination and to develop suitable regulations and drinking water standards. While 1,4-dioxane is more easily detected, concentrations can fluctuate rapidly making it challenging to quantify total contamination, link to sources, and treat. Furthermore, the long-term health effects of exposure are still not fully understood.

Mitigating impacts to public health will require proactive and highly adaptive regulations

The nature of these emerging contaminants create scientific and regulatory challenges that contribute to the disproportionate risk of exposure for communities near industrial sites, landfills, or wastewater treatment plants. Mitigating impacts to public health will require proactive and highly adaptive regulations. Given this summary of PFAS and 1,4-dioxane, regulators should consider the following actions:

- Develop regulation limiting 1,4 dioxane in drinking water and establish maximum contaminant level goals
- Require testing for PFAS compounds that reflect new and newly discovered PFAS species
- Establish regular testing for both 1,4-dioxane and PFAS at or downstream of industrial sources
- Improve transparency of industries developing these contaminants to enable research into environmental remediation
- Implement regular PFAS testing of treated solid waste from wastewater treatment facilities to prevent contamination of agricultural land via fertilizer application.

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