United States Analysis of the Regulatory Inception of Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water Policy among States and Review of Regulatory Efforts made by the Federal Environmental Protection Agency

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ABSTRACT

UNITED STATES ANALYSIS OF THE REGULATORY INCEPTION OF PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN DRINKING WATER POLICY AMONG STATES AND REVIEW OF REGULATORY EFFORTS MADE BY THE FEDERAL ENVIRONMENTAL PROTECTION AGENCY

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Per- and polyfluoroalkyl substances (PFAS) are emerging contaminants that are generating a pressing need for hasty policy to protect human health and the environment because they have not been regulated for decades. These chemicals have created legacy contamination widespread across the United States and have been introduced into the environment without legal directives since the 1950s. Current research shows that PFAS cause many serious health affects when bioaccumulated in the human body. State and federal governments are beginning to act on creating legislation to remediate current contamination and prevent further pollution from occurring. However, with the incipient nature of this PFAS issue, much research is lacking to completely understand elements surrounding the destruction and control of these chemicals in environmental media. While the federal government has only published proposed rulemakings for these substances, states have set the foreground for enacting PFAS legislation. The United States government has set out a comprehensive plan to address the PFAS issue but has yet to publish final rules due to the need for greater understanding in certain areas pertaining to PFAS. This research analyzes the driving factors for PFAS policymaking among states in regards to drinking water policies. Perceived and actual contamination were represented in explanatory variables that were hypothesized to be the main elements influencing policy among states. However, the only significant factor propelling PFAS policy within states, that was accounted for in this research, is the associated state's majority political party, p=8.47E-06. Perceived contamination within a state was represented by the number of military bases based on the national average, which resulted in an insignificant effect on state PFAS drinking water policy, p=0.189. Actual contamination within a state was represented by a data exceedance ratio based on the most recent occurrence data release for the Unregulated Contaminant Monitoring Rule 5 (UCMR 5) cycle, which provided data on 29 PFAS in public water systems across the nation. The UCMR 5 data exceedance ratio was also deemed insignificant in effecting state drinking water policy for PFAS, p=0.363. The outcome of this analysis is vital to understand that sometimes quick environmental policymaking is purely politically motivated and is premature, lacking scientific knowledge and comprehensive social and economic understandings.

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LIST OF ACRONYMS

11Cl-PF3OUdS	11-chloroeicosaflyoro-3-oxaundecane-1-sulfonic acid
4:2 FTS	1H, 1H, 2H, 2H-perfluorohexane sulfonic acid
6:2 Cl-PFESA	6:2 chlorinated polyfluoroalkyl ether sulfonate
6:2 FTS	6:2 Fluorotelomer sulfonate or 1H, 1H, 2H, 2H-perfluorooctane sulfonic acid
8:2 FTS	1H, 1H, 2H, 2H-perfluorodecane sulfonic acid
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid
AAL	Ambient Air Level
ADEC	Alaska Department of Environmental Conservation
ADONA	4,8-dioxa-3H-perfluorononanoic acid
AFFF	Aqueous Film-Forming Foam
ANPRM	Advanced Notice of Proposed Rulemaking
CAA	Clean Air Act
CCL	Contaminant Candidate List
CDC	Center for Disease Control
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CICI	Chemical Industry Council of Illinois
CUL	Clean-up Level
CWA	Clean Water Act
DOD	Department of Defense
EAFB	Eilsen Air Force Base
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EU	European Union
FTA	Fluorotelomer acid
FTOH	Fluorotelomer alcohol
GLM	Generalized Linear Model
HAP	Hazardous Air Pollutant
HBWC	Health-Based Water Concentration
HF	Hydrofluoric acid

PFAS	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutyric acid
PFBE	Perfluorobutylethylene
PFBS	Perfluorobutane sulfonic acid
PFBS-K	Perfluorobutane sulfonic acid, potassium salt
PFC	Perfluorocarbon
PFCA	Perfluorocarboxylic acid
PFDA	Perfluorodecanoic acid
PFDoDA	Perfluorododecanoic acid
PFDS	perfluorodecane sulfonic acid
PFEA	Perfluoroether acid
PFEESA	perfluoro (2-ethoxyethane) sulfonic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	perfluoroheptanesulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFIB	Perfluoroisobutylene
PFMBA	perfluoro-4-methoxybutanoic acid
PFMPA	perfluoro-3-methoxypropanoic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSA	Perfluorooctance sulfonamide
PFOS-K	perfluorooctane sulfonic acid, potassium salt
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentanesulfonic acid
PFTA	Perfluorotetradecanoic acid
PFTrDA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
PIC	Product of Incomplete Combustion

HFPO-DA	Hexafluoropropylene oxide dimer acid
IEC	Illinois Environmental Council
IMA	Illinois Manufacturer's Association
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MRL	Minimum Reporting Level
MWC	Municipal Waste Combustor
NAAQS	National Ambient Air Quality Standards
NCOD	National Contaminant Occurrence Database
NESHAP	National Emisstion Standard for Hazardous Air Pollutants
NEtFOSAA	N-ethyl perfluorooctancesulfonamidoacetic acid
NFDHA	nonafluoro-3,6-dioxaheptanoic acid
NHANES	National Health and Nutrition Examination Survey
NMeFOSAA	N-methylperfluorooctanesulfonamidoacetic acid
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulation
PAH	Polycyclic Aromatic Hydrocarbon
PFAA	Perfluoroalkyl acid

POP	Persistent Organic Pollutants
PTE	Potential-to-emit
PTFE	Polytetrafluoroethylene
PWS	Public Water System
RAA	Risk Assessment Advice
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
RQ	Reportable Quantity
SDVB	Polystyrene Divinylbenzene
SDWA	Safe Drinking Water Act
SNUR	Significant New Use Rule
SPE	Solid Phase Extraction
SSI	Sewage Sludge Incinerator
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UCMR	Unregulated Contaminant Monitoring Rule
UIC	Underground Injection Control
WWTP	Wastewater treatment plant

CHAPTER I

INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) has become a salient topic in the environmental regulation community. PFAS, which have been in use in the United States for decades, are emerging as a toxic group of chemicals that are incorporated in consumer products, firefighting foams, and industrial processes. Currently, there are no overarching federal policies that regulate these compounds in drinking water, air, products, or waste; nonetheless, at the time of this writing some regulatory actions have been proposed and are under review. As more research develops, the lack of regulation is concerning because new risks are uncovering the many harms of these substances. Following the course of environmental policy in modern times, states have become the principal actor at creating regulations for these chemicals that range from drinking water standards, disposal policies, and prohibition from food packaging and other consumer products.

Background

PFAS have been around for decades, but their emergence as toxic chemicals to human health and the environment have only been under urgent review in the past few years. These synthetic compounds started being developed in the 1930s-1940s and were being produced for consumer products by the 1950s (Interstate Technology Regulatory Council 2022a). Furthermore, occupational health studies in the 1970s were the origin of public health impact studies caused by PFAS, and environmental data has an even shorter history with these contaminants only arising in research in the early 2000s (Interstate Technology Regulatory Council 2022a). Many sources have different estimates as to the exact number of individual

PFAS chemicals, but most research studies have the list ranging in the thousands. However, the current EPA database, CompTox Chemicals Dashboard, lists over 9,000 chemicals in this group. A recent survey determined that of this substantial group, approximately only 256 are commercially relevant, even though many others may still be found in the environment (Interstate Technology Regulatory Council 2022a). This large chemical family has similarities in structure but differ in physical and chemical properties between individual species. These chemicals are anthropogenic and vary in their uses in consumer products and applications into industrial processes.

The synthesis of PFAS was a groundbreaking technology for use in consumer products due to their stain, water, grease, and thermal resistant properties. Common products containing PFAS include but are not limited to clothing, cosmetics, food packaging, carpets, furniture, outdoor equipment, adhesives and sealings, and non-stick cookware. Dupont, and now spinoff company, Chemours is a major manufacturer of PFAS chemicals and an early polluter through industrial discharges (Wagner 2023). Dupont is most famously known for their Teflon products, which all contain PFAS chemicals including polytetrafluorethylene (PTFE) and perfluorooctanoic acid (PFOA). Another major producer and legacy contaminator of PFAS is the 3M company, known widely for the Scotchgard product containing perfluoro octane sulfonic acid (PFOS). However, PFOA and PFOS being the two of the most studied PFAS compounds, including toxicity effects on the environment and human health, have been voluntarily phased out of production in the United States in the early 2000s due to such associated risks.

The United States Department of Defense (DOD) has also contributed to the PFAS problem with their major use of Aqueous Film-Forming Foam (AFFF). As mentioned, PFAS have high thermal resistance capabilities and have been used in fire-fighting foams to put out highly flammable and highly hazardous liquid fires. AFFF is used specifically for fires occurring at military sites, airports, petroleum refineries, bulk storage facilities, and chemical manufacturing plants (Interstate Technology Regulatory Council 2022a). These types of foams have been used by DOD for over 50 years and has potentially contaminated more than 700 areas around military sites across the United States (Environmental Working Group 2023).

Definition

PFAS have a variety of definitions, but as defined by the United States Environmental Protection Agency (EPA) in a proposed rulemaking for manufacturer reporting, "…the structural definition of PFAS includes per- and polyfluorinated substances that structurally contain the unit R-(CF2)-C(F)(R′)R″. Both the CF2 and CF moieties are saturated carbons and none of the R groups (R, R′ or R″) can be hydrogen" (EPA 2021). The CF constituent of the chemical is a middle or end atom that has a single carbon-fluorine bond, while the CF2 constituent of the chemical structure is the atom containing two carbon-fluorine bonds. An R group is a loose definition for any other atom, alkyl chain, or functional group attached to the main carbon backbone.

Perfluoroalkyl species have all carbon atoms in the chain completely saturated with fluorine atoms, whereas polyfluoroalkyl species may have some carbon atoms completely saturated with fluorine while other carbon atoms can be connected to a hydrogen atom. With the notable presence of fluorine atoms in these compounds, the strong electronegativity causes a short and very stable bond between the carbon and fluorine atoms (Wang et. al. 2022). These bonds make PFAS extremely persistent in the environment and are highly prone to degradation, coining them with the nickname "Forever Chemicals." These compounds are similar in structure to fatty acids in which they have a hydrophobic tail, the carbon-fluorine alkyl chain, and a hydrophilic head, the attached polar functional group (Interstate Technology Regulatory Council 2022). See Figure 1 below for a depiction of the PFOS and PFOA structure separated in the head/tail groups as described.

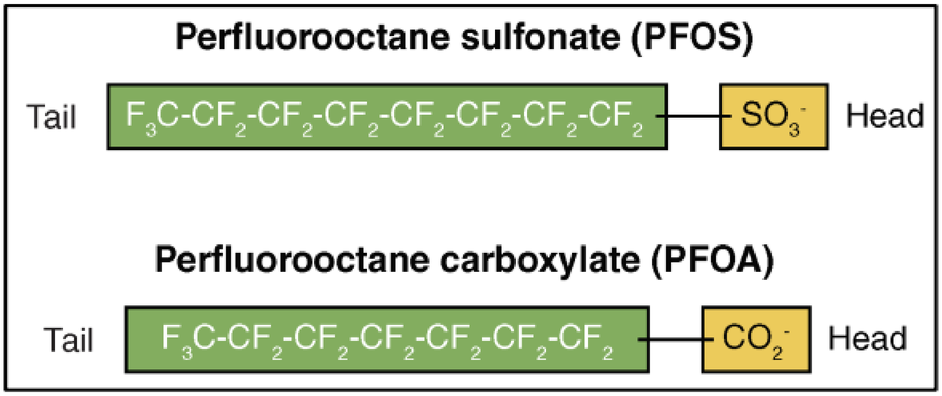


Figure 1: The tail and head structure of PFOS and PFOA (Interstate Technology Regulatory Council 2022)

One of the main identifying factors in different types of PFAS is the carbon chain length. Typically, long-chain PFAS will contain eight or more carbon atoms in the alkyl chain and are commonly referred to as legacy PFAS. These compounds are dubbed legacy PFAS because they were the early manufactured chemicals that have since been phased out of production in several developed countries. Short-chain PFAS have been manufactured to replace some of the legacy PFAS and will contain less than eight carbon atoms. In addition to the carbon-chain length, another PFAS identifying factor is the attached functional group to the alkyl chain. Subclasses of PFAS are often categorized by their functional groups. These include, but are not limited to, perfluoroalkyl acids (PFAAs), perfluoroether acids (PFEAs), fluorotelomer acids (FTAs), fluorotelomer alcohols (FTOHs) (Brase et. al. 2021), perfluorocarbons (PFCs), and fluoropolymers (Wang et. al. 2022). See Figure 2 below, which depicts some of these subclasses of PFAs with an example chemical structure for reference of each.

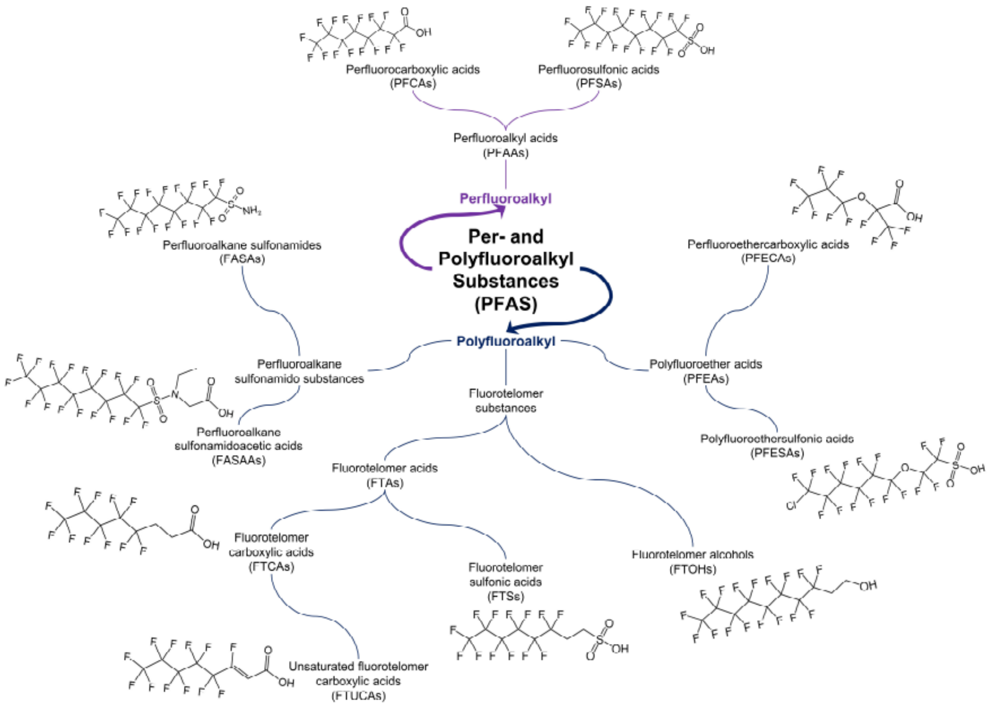


Figure 2: Classes and subclasses of PFAS chemical along with general chemical structure for each class (Brase et. al. 2021)

Extent of Contamination

PFAS contamination has been widespread over the past couple of decades. Their unique structure correlates PFAS to surfactant chemicals, meaning they have the ability to reduce surface tension in liquids. As previously stated, PFAS are extremely persistent in the environment due to their non-degradation properties. PFAS also exhibit hydrophobic and lipophobic effects, electrostatic interactions, and interfacial behaviors (Interstate Technology Regulatory Council 2022). These properties allow for interactions with organic carbon in soil and accumulation along environmental media intersections including soil/water and water/air (Interstate Technology Regulatory Council 2022).

Understanding fate and transport mechanisms of PFAS chemicals is vital to comprehension of the extent of contamination and ways to remediate harms in the environment. “Fate and transport” is defined as “how the nature of contaminants might change (chemically, physically, or biologically) and where they go as they move through the environment" (Center for Disease Control and Prevention 2022). PFAS compounds can manifest anionic, cationic, and zwitterionic states depending on the specific chemical. The anionic species have higher mobility in groundwater, whereas cationic and zwitterionic species tend to sorb more into soil and sediments (Interstate Technology Regulatory Council 2022). Additionally, legacy PFAS tend to be slower while moving throughout environmental media than their short-chain counterparts.

PFAS can navigate easily through the environmental media, but the concentration of chemical is generally not reduced through their movement. Transport processes include water and ground movement, air movement, and leaching. Changes in water velocities can diffuse PFAS molecules in multiple directions, which may change the media distribution (Interstate Technology Regulatory Council 2022). PFAS, as a group, typically have low volatility but experience air transport mainly from industrial emissions. Some PFAS can undergo photooxidation, but most airborne chemicals will end up in water or soil surfaces through both wet and dry deposition (Interstate Technology Regulatory Council 2022). Leaching can also occur for PFAS present in soil, which can describe how PFAS ultimately invade groundwater sources. Moreover, PFAS in landfills without proper leachate control can allow PFAS to enter soil and groundwater sources through leaching (Interstate Technology Regulatory Council 2022).

Contaminated PFAS sites continue to increase in number across the United States. As of August 2023, 3,186 locations across 50 states, the District of Columbia, and two territories have displayed high levels of PFAS (Environmental Working Group 2023a); see figure 3 below. Current understanding of PFAS contamination is limited and biased on locations with well-developed testing programs. However, it can be presumed that environmental contamination has a point of generation from three major types of sites: AFFF discharge sites, certain industrial facilities, and sites related to PFAS-containing wastes (Salvatore et. al. 2022).

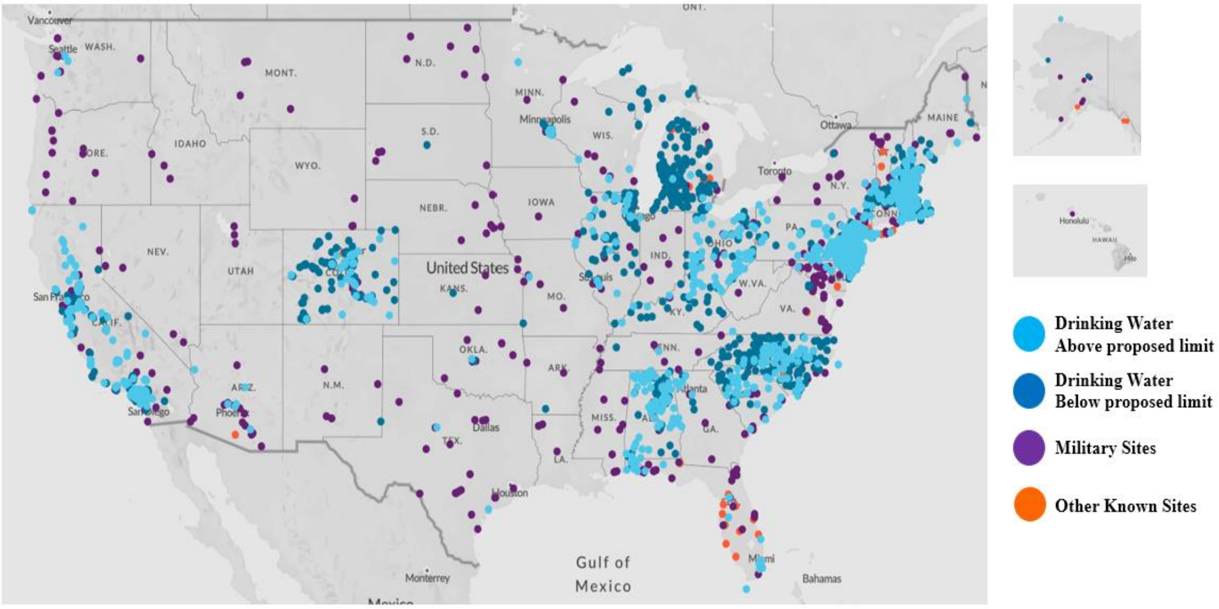


Figure 3: United States PFAS Environmental Contamination as of August 2023 (Environmental Working Group 2023a)

AFFF discharge sites can include military sites and training operative locations, major airports, firefighting training sites, and high-hazard flammable liquid fire sites. Although many training practices involving AFFF has ceased, the PFAS-containing foams are still used by the DOD, at airports, and at other sites containing large flammable liquid hazards. AFFF can easily enter and disperse into environmental media around these sites and travel some distance from the point of origin. Manufacturers and other industrial facilities that produce or utilize PFAS in their daily operations can also be a major contributor of environmental contamination through discharges to water and discharges to air through stack emissions (Salvatore et. al. 2022). Furthermore, PFAS-waste sites, including wastewater treatment plants, landfills, or incinerators can add to polluted areas in similar ways as industrial facilities. Wastewater treatment plants also produce additional hazards by distribution of contaminated biosolids to agricultural lands (Salvatore et. al. 2022).

Impact on Public Health

With widespread PFAS contamination and exposure to human populations, there arises concern on the effects humans will experience when unprotected from these substances. Overall, PFAS are extremely persistent in the environment and the human body (Gullett and Gillespie 2019). Human exposure to PFAS can occur in a variety of ways and can have detrimental consequences when exposed. The main route of exposure happens through direct ingestion or inhalation. PFAS can be ingested through contaminated drinking water, contaminated crops and livestock, or through leaching from food packaging. Inhalation can occur through manufacturing processes that can release PFAS chemicals or constituents into the air. Additionally, these chemicals bioaccumulate throughout the food chain in aquatic and terrestrial species. Diets which include high fish consumption can lead to higher PFAS levels in human systems and human populations with fish as the main protein (Brennan et. al. 2021).

The United States Center for Disease Control (CDC) has been conducting biomonitoring surveys for PFAS since 1999 and has identified at least 12 compounds in blood serum of the sampled population (Center for Disease Control and Prevention 2022a). Collection of data is done through the United States National Health and Nutrition Examination Survey (NHANES). This survey is a participant-based study, including individuals aged 12 years or older, in which results are used by scientists to predict levels of environmental contaminants in the general United States population (Center for Disease Control and Prevention 2022a). The 1999-2000 NHANES tested 1,562 participants, and four PFAS compounds- PFOA, PFOS, perfluorohexane sulfonic acid (PFHxS), and perfluorooctanesulfonamide (PFOSA)- were detected in every person

(Calafat et. al. 2007). An additional three PFAS were detected in greater than 90% of the sampled population. In the NHANES 2003-2004 report, PFAS contaminants, including PFOA, PFOS, PFHxS, and perfluorononanoic acid (PFNA) were found in greater than 98% of persons sampled (Calafat et. al. 2007a). Although a large percentage of people still had PFAS contaminants detectable in their blood serum, mean concentrations for PFOA, PFOS, and PFHxS were lower in the 2003-2004 study (Calafat et. al. 2007a). This shift is most likely due to the phaseout of PFOS and PFOA manufacturing by 3M and other manufacturers in the United States, thus lessening exposure to the U.S. population. The 2013-2014 NHANES report continues to show detectable PFAS concentrations of PFOA, PFOS, PFHxS, and PFNA in nearly all of the American population (Brennan et. al. 2021).

Although PFAS are being identified in the majority of the population, there is a lot of uncertainty regarding direct health effects of these contaminants in the blood. PFOA and PFOS have been shown to cause negative effects in laboratory animals including reproductive and developmental issues, liver and kidney issues, and immunological issues (EPA 2020). There has been some research conducted for human epidemiology, and results from being exposed to PFAS largely include higher cholesterol levels and some instances of infant birth weight effects, immune system effects, and thyroid hormone disruption (exposure to PFOS) (EPA 2020). Additionally, many research studies have suggested a possible link to various cancers from exposure to PFAS (American Cancer Society 2023). The limited evidence available throughout studies has deemed PFOA a possible carcinogen (American Cancer Society 2023).

In addition to independent research, the United States EPA is working to complete toxicity assessments for individual PFAS. Toxicity assessments generally describe what harm a chemical can cause at specific concentrations. Assessments have been completed for PFOA, PFOS, hexafluoropropylene oxide dimer acid (HFPO-DA), the C4 version of PFOA also referred to as GenX chemicals, and perfluorobutane sulfonic acid (PFBS), the C4 version of PFOS. PFNA is in phase one of its' toxicity assessment, and PFHxS is in phase three of the toxicity assessment.

State and Federal Actions

With the lack of urgency at the federal level up until recently, states have spearheaded action in regulating PFAS chemicals. These actions include regulating chemicals in consumer products, drinking water, fire-fighting foams, and disposal methods. Currently, 33 states have 197 policies that address PFAS in these areas (Safer States 2023). In 2019, there were over 100 bills in state legislatures containing PFAS directives (Hildreth and Oren 2021). The number continued to rise in 2020 with more than 180 bills in states being considered for adoption to help fight the PFAS crisis (Hildreth and Oren 2021). In addition to the policy-development, states are also considering PFAS contamination by appropriating funds for research and beginning PFAS take-back programs for certain products and fire-fighting foams (Hildreth and Oren 2021).

Drinking water policies are most common among states with enforceable standards and health-based guidance levels. After drinking water, the most widespread action against PFAS among states includes fighting their manufacture in consumer products, including food packaging, and phasing the chemicals out of fire-fighting foams (Safer States 2023a). Other environmental areas, including air and soil, have also gained attention among state policy-makers. While there are fewer of these policies as compared to water and consumer products, states are attempting to regulate PFAS contamination at these stages as well. Additionally, few states have taken actions preventing PFAS from undergoing certain end-of-life disposal methods, including incineration and landfilling operations. Further analysis on states' actions against PFAS will be included in Chapter 2 and 3.

The federal government has taken a more leisurely approach than the states at regulating PFAS and at providing meaningful policies to reduce the spread of contamination in the environment and reduce the impact on public health. The United States EPA has created a formal PFAS Action Plan that was introduced in 2019, which produced short- and long-term goals for the agency to tackle the PFAS issue (Hildreth and Oren 2021). A more comprehensive outline for PFAS action was released on October 18, 2021, and was deemed the PFAS Strategic Roadmap (EPA 2021a). The EPA's Roadmap provides a detailed timeline for addressing PFAS in areas concerning environmental contamination, public health, and holding manufacturers accountable for pollution (EPA 2021a). The deadlines for specific actions range between the years 2021-2024 and focus mainly on research, restriction, and remediation (EPA 2021a). Although this document creates a plan for PFAS, there is not much regulatory action being developed through the roadmap, rather providing a scientific foundation to later use in PFAS statutes. More information is analyzed into the progress of the EPA's PFAS Strategic Roadmap in Chapter 2 and 3.

Federal Regulatory Acts

There are numerous environmental regulations at the federal level that protect public health and the environment from toxic contaminants. The Toxic Substances Control Act (TSCA) regulates new and existing chemicals through reporting, record-keeping, and testing requirements. Under TSCA is the Significant New Use Rule (SNUR) which addresses chemicals new to commerce and risks associated with those chemicals. The Emergency Planning and Community Right-to-Know Act (EPCRA) is another environmental statute that requires certain industries to report on chemical releases through the Toxics Release Inventory (TRI). 172 PFAS compounds were added to TRI in the reporting year 2020, and additional compounds are being added to the list each year. Although these environmental regulations both deal with PFAS chemicals through reporting requirements, there are no standards that must be followed in regards to chemical releases and contamination. The federal statutes that will be evaluated in this research include the Clean Water Act (CWA), the Clean Air Act (CAA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Resource Conservation and Recovery Act (RCRA).

The CWA is the collection of environmental regulations that manage pollutants and chemicals in waters of the United States. Included under the CWA is the Safe Drinking Water Act (SDWA) that sets specific standards for chemicals allowed in public drinking water. PFAS started being monitored and regulated under the SDWA in 2009, when the EPA first issued health advisories for PFOA and PFOS (Brennan et. al. 2021). However, these advisories were non-enforceable standards that were merely suggested as a safety measure for public health. In the spring of 2023, the EPA took a major action under the CWA and proposed the first drinking water standards for six PFAS under the National Primary Drinking Water Regulation (NPDWR). Further explanation and analysis on this topic will be discussed in Chapter 2. Also included under the CWA are National Pollutant Elimination Discharge System (NPDES) permits. NPDES permits are issued by the federal or state EPA and give accessibility to industries to discharge pollutants from a point source into the waters of the United States. PFAS can be regulated in this way to prevent high concentrations of contaminants entering water systems, but are only specific to a facility-by-facility basis, meaning that not all facilities have these contaminants added to NPDES permits as well as some facilities having variations in standards.

The federal environmental framework for air pollutants is the Clean Air Act (CAA). This Act regulates chemical emissions from mobile and stationary sources. There are many types of standards contained in the Clean Air Act including National Ambient Air Quality Standards (NAAQS) and National Emission Standards for Hazardous Air Pollutants (NESHAPs). The NAAQS regulations only control for six criteria pollutants, carbon monoxide, ozone, sulfur dioxide, nitrogen oxides, and particulate matter, throughout regions in the United States. However, NESHAP standards could easily be applied to PFAS discharges at industrial sites. In this way, there would be a specific standard that would allow a certain amount of PFAS to be emitted into the atmosphere. In addition to a standard, NESHAPs typically cover other areas required by businesses and manufacturers including monitoring, recordkeeping, and reporting requirements. This could be done on a chemical-by-chemical basis or by a class. Previous setbacks with developing CAA regulations have been a lack of technology and approved methods to measure the amount of PFAS in air emissions. While methods still are in beginning phases for measuring PFAS in ambient air, source emissions do have EPA approved methods currently. See Chapter 2 for additional details regarding approved analytical methods for PFAS detection in air emissions from point sources.

CERCLA, also known as Superfund, is a federal environmental statute that holds chemical companies responsible for the clean-up of hazardous chemicals that threaten public health or the environment. This Act specifically creates liability for abandoned hazardous waste sites and any harmful releases that may occur at those sites during operation. RCRA is the environmental law that manages hazardous and non-hazardous solid waste. These regulations implicate a cradle-to-grave procedure for hazardous chemicals from the point of generation to the ultimate disposal of the waste.

In the process for chemicals to become classified as hazardous, they must be listed under CERCLA or RCRA. Designating chemicals as hazardous substances under CERCLA requires a process including a Human Health Risk Assessment. There is planning involved before starting the assessment, and completing the process includes a four-step method: (1) hazard identification; (2) dose-response assessment; (3) exposure assessment; and (4) risk characterization (EPA 2023e). RCRA requirements for labeling chemicals as hazardous is a less rigorous task, which focuses mainly on the particular qualities and characteristics of a chemical to list it. Once a chemical is deemed a hazardous substance under RCRA, the designation gets adopted by the other CERCLA immediately. This is due to the definition of "hazardous substance" under CERCLA which signifies other statutory lists for hazardous chemicals including Clean Water Act Hazardous Substances outlined in section 311, Clean Water Act Toxic Pollutants outlined in section 307(a), Clean Air Act Hazardous Air Pollutants outlined in section 112, Resource Conservation Recovery Act Hazardous Wastes outlined in section 3001, and Toxic Substances Control Act section 7 (EPA 2023b). The reverse situation is not true because a CERCLA hazardous substance designation is automatically adopted by RCRA, since the RCRA hazardous waste definition does not include the list of hazardous substances under CERCLA. The quickest path to getting PFAS regulated as hazardous substances would be for these chemicals to be regulated under RCRA first and adopted over to CERCLA. However, the process for designating PFOA and PFOS as hazardous chemicals has already begun under CERCLA. Although this may take longer to see any tangible action, federal regulators are making some progress toward the goal. See Chapter 2 for a more detailed description on the actions being taken to list certain PFAS as hazardous substances.

Chemicals can be classified as hazardous waste in two ways: either as a characteristic hazardous constituent or a listed hazardous constituent. All hazardous chemicals are assigned a waste code beginning with a letter, followed by a three-digit number. A characteristic hazardous chemical has to exhibit one of these four characteristics- ignitability (001), corrosivity (002), reactivity (003), and toxicity (004-043). Characteristic hazardous wastes are identified by a D and the following number associated with the specific hazard. Listed hazardous chemicals are registered on one of four lists- F, K, P, and U lists. These inventories are found in the Code of Federal Regulations (CFR) part 261. Listed hazardous wastes have a waste code letter that corresponds with the list that contains that chemical and number assigned to the chemical.

As mentioned earlier, PFAS are a massive group of chemicals, and the best way to regulate these compounds does not have a clear trajectory. There are four different approaches policy-makes can take when assessing how to manage PFAS; these include the single chemical approach, chemical mixture approach, class approach, and arrowhead approach (Kempisty and Racz 2021). The single chemical approach is perfectly accurate to its title- regulating each individual PFAS compound separately. This method would be the most reliable to account for hazard and toxicity differences between each chemical. However, there are serious drawbacks considering the amount of time and resources required to carry-out this approach. The chemical mixture approach is a more comprehensive method involving groups of chemicals. This type of technique has been used for chemical groups of dioxins and polycyclic aromatic hydrocarbons (PAHs) (Kempisty and Racz 2021). Although this has been used, it is uncommon for regulatory agencies to use the chemical mixture approach because it requires the research of cumulative impacts of the group being regulated in addition to the effects of each chemical individually.

The third option is the arrowhead approach, or sometimes referred to as the subclass approach. This method chooses an arrowhead chemical to regulate that is already well characterized and can be utilized as the standard for a group of related chemicals. PFAS have already been addressed under the arrowhead method at the Stockholm Convention and Europe's Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) program (Kempisty and Racz 2021). A specific example of the arrowhead method is the regulation of PFOA, its salts, and its precursors or PFOA-related compounds. In this situation, PFOA would be the arrowhead compound and would set the standard for the related PFAS. While the arrowhead method is more extensive than the first two approaches, there may occur some unwanted hazards or risks if the representative group contains chemicals that may be more toxic than the arrowhead species (Kempisty and Racz 2021).

Finally, the class approach is the regulation of chemicals as an entire class, or all compounds under a related group. For PFAS to be regulated as a class of compounds, the persistence and common carbon-fluorine bonds could provide a legitimate basis to group these chemicals together (Kempisty and Racz 2021). This method would be the most feasible regarding time and resources, and several states have already chosen to regulate PFAS as a class. The obvious disadvantage to this method is that many specific hazards or toxic properties could potentially be overlooked when grouping together such a large number of compounds.

International Actions

The Stockholm Convention on Persistent Organic Pollutants (POPs) was adopted internationally in 2001 and was enacted as international environmental law in 2004 (Brennan et. al. 2021). This convention has been cited as the most significant international policy concerning environmental contaminants (Brennan et. al. 2021). This convention began addressing PFAS in

2009 when PFOS and its derivatives was banned from production and eliminated in most non-essential uses. In 2019, PFOA, its salts, and PFOA-related compounds were added to the manufacture ban in this international policy (Brennan et. al. 2021). Additionally, in 2022, PFHxS, its salts, and PFHxS-related compounds were added to the list of POPs to eliminate use (Organization for Economic Cooperation and Development 2023). The Stockholm Convention has been ratified by 152 countries, excluding the United States whom signed on to the convention but has yet to ratify (Brennan et al. 2021). Some signatories of the Stockholm Convention throughout Asia and South America have implemented the PFAS-related bans in a selective way but fail to regulate other PFAS compounds or PFAS uses in their countries (Brennan et. al. 2021).

In the European Union (EU), an overarching policy called REACH addresses chemical production and toxicity effects of chemicals on the environment and human health. The above listed PFAS banned throughout the Stockholm Convention have been added to the EU's REACH list, barring their production and non-essential use in products (Organization for Economic Cooperation and Development 2023). Germany, Sweden, and Norway are leading countries in the EU for PFAS research and drive to add more individual PFAS chemicals to REACH (Organization for Economic Cooperation and Development 2023). Canada has also begun addressing PFAS by a combination of governmental regulation and industrial voluntary agreements, which came to fruition in 2015 with eradication of manufacturing PFOS, PFOA, long-chain perfluorocarboxylic acids (PFCAs), and their precursors (Brennan et. al. 2021). Australia's focus on addressing PFAS has been similar in nature to the United States approach. Instead of national standards and regulations, the Australian government is relying on states and territories to regulate how they see fit for the local area (Brennan et. al. 2021). The Stockholm

Convention concerning PFAS bans have not yet been ratified in Australia, but the states are taking action to address PFAS in food, food packaging, and fire-fighting foams, while also conducting research on contamination and remediation efforts (Brennan et. al. 2021).

Conclusion to Chapter I

Chapter 1 has provided a general introduction to PFAS. This large class of compounds have been deemed the "forever chemicals", as coined by their high resistance to degradation. However, this popular phrase used in news and media outlets can create panic for the general public, whom are just being introduced to these contaminants in small snippets. The term "forever" can be ominous in terms of the public's perception that there is no resolve to the environmental contamination and human exposure suffered from the legacy pollution. However, as discussed later in this research, there are solutions to break down PFAS and ways to address the current and future contamination from these compounds. It is important to be aware of how, as researchers, we discuss PFAS amongst peers with non-scientific backgrounds.

Historical uses for PFAS provided an opportunity for manufacturers to easily produce consumer products with water, stain, grease, and thermal resistant properties. This led to widespread contamination in the United States, which has become an urgent issue for environmental degradation and public health. The need for regulatory action is ominous, because the United States is only recently addressing the issue through proposed environmental policies. States have taken the lead in trying to protect human health and the environment from these toxic substances but due to federalism the compliance is ad hoc. Additionally, international measures have been taken to restrict further production and contamination of select PFAS compounds.

In Chapter 2, a literature review is provided that will provide a deeper examination into the regulation of PFAS in state and federal environmental policy. Current state policies are also scrutinized to describe how and why these legislatures are taking the central and only regulatory framework with these compounds. Additionally, previous research will be analyzed to better understand the disposal and destruction methods for PFAS. Chapter 3 presents the statistical objectives in this research. A micro-analysis and macro-analysis of state PFAS policies were completed, in addition to an examination of federal policy actions. In Chapter 4, the research findings will be discussed, along with the many limitations this study has faced due to the emergence and current nature of the PFAS issue.

CHAPTER II

LITERATURE REVIEW

Policy Process

Creating environmental policy typically experiences a six-step process including agenda setting, policy formulation, policy legitimation, policy implementation, policy and program evaluation, and policy change (Kraft 2022). The first step of the process, agenda setting, refers to the environmental issues gaining popularity among the public, interest groups, stakeholders, and policymakers. This includes the way the issue is perceived and the tone in which it is being discussed among interested parties. Secondly, policy formulation is the beginning stage of developing a plan of action. Through the research of science, economics, and policy analysis, goals and strategies are created at this stage to address the environmental issue (Kraft 2022). Policy legitimation is the step in the process in which the plan for regulation is introduced to the public in order to gain support of the initiatives. In this step, governmental actions are explained and justified with regards to protection of public health and the environment while also maintaining feasibility (Kraft 2022). The policy implementation stage is the first stage after the policy has been written into legislation. At this phase, administrative agencies are responsible for carrying out duties associated with compliance with the new policy (Kraft 2022). The last two stages of the policy process are policy and program evaluation, and policy change. The evaluation step is when agencies review the success or failures of the implemented policy (Kraft 2022). Policy change is in direct correlation with the evaluation step. If a policy has been deemed to fail overall in comparison to its successes, the policy can be altered through statutory change (Kraft 2022).

Although the six steps seem to be in a logical and sequenced order, they do not have to be performed in order and are often intertwined. For example, policy evaluation happens in between many of these stages individually and does not only occur after time has passed for a newly active policy. Additionally, it is important to note that this is not a quick process in most cases associated with environmental policy. The issues involving environmental policy in the 21st century are often complex and comprise many powerful stakeholders with strong interests in new policy development.

The previous statement could not be more obvious in the issues surrounding PFAS. Agenda setting for PFAS policy has been growing over the past several years, with salience extending to the general population. The conversations are still aplenty with manufacturers facing heavy class action lawsuits, new findings about PFAS in groundwater sources across the United States, and consumer products claiming items are free of PFAS. Although the agenda may have already been set for some areas, the policy formulation step is slowly coming to fruition with very few plans and policies developed regarding PFAS. These few proposed rules are in the policy legitimation phase where the public and interested parties are being asked for feedback during comment periods on the rules. Additionally, there have been many attempts made to educate the public from the EPA and other local agencies and environmental groups about the dangers of PFAS and the action needed to protect the public from these harmful substances. The issue with growing salience and so much information is that it may create a panic that leads to regulatory decisions not influenced by scientific information. As noted in Chapter 1, many states have already begun regulating PFAS; however, the federal government seems to be taking their time to ensure they are creating policies based on the best available scientific evidence. In this chapter, a summary is given of the policy efforts surrounding PFAS at the state and federal levels, in addition to scarcely available scientific research that has been done in relation to these policies.

PFAS Analytical Detection Methods

Developing policy for emerging contaminants requires extensive research on the front end before meaningful policies can be promulgated. However, in addition to studying the chemical characteristics, developing standardized analytical methods for detecting these compounds must also be done before proper monitoring in environmental media can take place. The US EPA is the main administrative agency responsible for producing analytical methods regarding contaminants in environmental media. Currently, there are only approved EPA methods for drinking water sources, other aqueous sources (including groundwater, surface water, and wastewater), and air emissions from stationary sources (EPA 2023a).

The two final approved methods for detection of PFAS in drinking water are EPA Method 537.1 and EPA Method 533 (Office of Water 2023). These methods were developed to support regulatory efforts under the SDWA (American Water Works Association 2021). Both methods incorporate a liquid chromatography with tandem mass spectrometry procedure. The original Method 537.1 was only viable for 14 individual PFAS (Phenomenex 2022). In 2018, Method 537 was updated to be applicable for the original 14 PFAS but with an addition of 4 shorter chain PFAS (Phenomenex 2022). The updated Method 537.1 requires the use of a polystyrene divinylbenzene (SDVB) cartridge during the solid phase extraction (SPE) portion of the procedure, which can sometimes lead to uncertainty and low recovery of short-chain PFAS (Phenomenex 2022). This is what ultimately led to the creation of Method 533 in 2019. Method 533 includes 25 individual PFAS that can be analyzed under this technique (Alpha Analytical 2023). The main difference between the two analytical procedures is that Method 533 requires the "use of extracted internal standards as part of an isotopic dilution quantification approach whereas" (Alpha Analytical 2023). This isotope dilution step reduces uncertainty. Additionally, in comparison to the SDVB cartridges required under Method 537.1, Method 533 uses a weak anion exchange SPE cartridge, which allows for more individual short-chain PFAS to be analyzed accurately (Alpha Analytical 2023). There is some overlap between constituents analyzed on both methods. Overall, between the two lists, there are only 29 PFAS that can be analyzed in drinking water using the two methods combined.

EPA Method 8327 was finalized in 2021 and is an analytical method use for surface water, groundwater, and wastewater matrices. This method was developed to support regulatory efforts for solid waste under RCRA (American Water Works Association 2021). Method 8327 can be used for detection of 24 specific PFAS constituents and is similar to the drinking water methods in that it employs a liquid chromatography with tandem mass spectrometry procedure (EPA 2023a). In addition to EPA Method 8327, there is a secondary EPA method that could be used for detection of PFAS in water sources besides drinking water, EPA Method 1633. However, EPA Method 1633 is only in the draft phase, since this is still under development and validated by a single laboratory (EPA 2023a).

Apart from water source detection methods, the US EPA has also developed several methods for PFAS detection in air from stationary/point sources. EPA approved method- Other Test Method (OTM) 45- has the capability to test for 50 PFAS compounds from sources, as well as identify additional chemical species found in the sample (EPA 2023a). Furthermore, there are two other EPA approved methods for PFAS air testing including SW-846 Test Method 0010: Modified Method 5 Sampling Train for semi-volatiles and non-volatiles and Modified Method TO-15 for volatiles (EPA 2023a). As mentioned in Chapter 1, EPA approved methods for PFAS detection in ambient air are still in the development stages. There are three methods deemed “Coming Soon” by the EPA for ambient air but a target date for these has not been released yet (EPA 2023a).

EPA's Unregulated Contaminant Monitoring Rule

Under the SDWA Amendments of 1996, EPA created the Unregulated Contaminant Monitoring Rule (UCMR) which set a goal to monitor for specific contaminants lacking health-based standards under the Act (EPA 2023g). These amendments established a framework for the UCMR program indicating that a strategy for monitoring priority contaminants in drinking water every five years be made, criteria for which and how many public water systems must be included, and data collection be stored in a National Contaminant Occurrence Database (NCOD) (EPA 2023g). The purpose of UCMR is to assist the Agency in decision-making with regards to policies regulating these emerging contaminants that may pose a threat to public health. At public water systems serving less than 10,000 citizens, EPA covers the costs associated with the collection of monitoring data under this rule to relieve the otherwise financial burden these small facilities would have endured (EPA 2023g).

The UCMR monitoring data is collected for the designated contaminants for that cycle in three-year intervals. Although monitoring occurs over 3 years, this program is typically a five-year process which includes time before the monitoring event to finalize the list of contaminants and publish this list in the Federal Register. When considering the contaminants to be chosen for each cycle, the EPA reviews the Contaminant Candidate List (CCL) and other chemicals of high priority (EPA 2023g). The CCL was developed in conjunction with UCMR and for a contaminant to be included on the CCL, it must not be currently regulated under an NPDWR, known to be present or thought to be present at public water systems, and may call for future regulation under the SDWA (EPA 2023g). Typically, the EPA tries to include contaminants not previously monitored under a UCMR cycle and have a validated method for monitoring in drinking water. Additionally, other factors considered when determining the next group of contaminants to add to a UCMR include health information, public interest, active use, and availability of occurrence data (EPA 2023g). Finally, stakeholder input and cost-effectiveness are examined when making the ultimate determination. Each UCMR may contain up to 30 contaminants (EPA 2023).

To date, there have been four completed UCMR cycles. The UCMR 5 cycle is in progress. PFAS made their first appearance to UCMR in cycle 3, for the monitoring dates of 2013-2015. In UCMR 3, 28 chemicals and 2 viruses were on the list for data collection (EPA 2023g). Of the 28 chemicals, 6 PFAS were included- PFOA, PFOS, PFNA, PFHxS, perfluoroheptanoic acid (PFHpA), and PFBS. UCMR 4, 2018-2020, did not include any PFAS in the contaminant list for that cycle. UCMR 5 has included 29 PFAS and lithium in the monitoring inventory for the years 2023-2025. See Chapter 4, Table 3, for information regarding the specific PFAS monitored in the UCMR 5 cycle. Although the EPA prefers not to include contaminants monitored in previous UCMRs, the 6 PFAS in UCMR 3 are included in UCMR 5. This is most likely due to advances in technology allowing for analytical equipment to detect smaller amounts of PFAS in water. More information and analysis are provided in Chapter 3 on the PFAS occurrence data collected in UCMR 3 and the initial release of data for UCMR 5.

Water Policies by State

Water policy is the most widely adopted legislation across states in the PFAS category. New Jersey was the first state to set a maximum contaminant level (MCL) for a PFAS chemical in drinking water in 2018 (Hildreth and Oren 2021). MCL’s are enforceable standards for contaminants in drinking water, as opposed to health advisories which are simply suggested levels to harness public safety. Other states with enforceable drinking water standards include Maine, Massachusetts, Michigan, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, and Wisconsin (Safer States 2023). Many other states have PFAS health advisories or screening levels for drinking water, while some are also in the process of adopting enforceable limits. These states include Alaska, California, Colorado, Connecticut, Hawaii, Illinois, Maryland, Minnesota, New Mexico, North Carolina, Ohio, Oregon, and Washington (Safer States 2023). Delaware and Virginia are both in the process of adopting drinking water standards for PFAS (Safer States 2023).

Health advisory levels do not require regulatory compliance, but serve more as guidance to protect public health. The extent of action required with health standards varies by state. Colorado has issued health advisory levels for several PFAS. However, if these PFAS are not included in a facility's NPDES permit, there is not really consequence to dumping PFAS greater than their standard into surface waters (Olson 2021). Delaware has adopted the EPA's health advisory levels for PFOA and PFOS, which when these levels are exceeded in drinking water sources, the state requires a response plan by the public water system to be developed to ensure drinking water is safe to consume (DNREC 2023). Health based-guidance between states has high variation, with some standards decidedly strict while others are more lax. Without a federally-issued standard for PFAS in water, some states with health advisories may still not be protecting their citizens health sufficiently.

Besides drinking water, there are many states that also have PFAS standards related to groundwater and surface water. Groundwater is indirectly connected to drinking water standards. The basis for protecting groundwater from contamination can help ensure that public water systems and private wells do not contain levels of contaminants that are harmful to human health. Many states have developed groundwater standards for PFAS; some of which have both groundwater and drinking water standards while others have solely groundwater protection. States with standards for PFAS in groundwater only include: Delaware, Florida, Indiana, Iowa, Montana, and Texas (Interstate Technology Regulatory Council 2023). States with protection against PFAS in both groundwater and drinking water sources include: Alaska, Colorado, Connecticut, Hawaii, Illinois, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, North Carolina, Pennsylvania, Rhode Island, Vermont, and Washington (Interstate Technology Regulatory Council 2023). Surface water standards are created to ensure safety of fish consumption and recreational activities that occur in the body of water. Protection of surface water from PFAS is indirectly connected to protecting human health in these ways. States with surface water standards for PFAS include: Alaska, Colorado, Florida, Michigan, Minnesota, New York, Oregon, and Wisconsin (Interstate Technology Regulatory Council 2023).

Air Policies by State

Air emissions of PFAS have not been regulated as strongly or quickly as the policies established by states for PFAS in water. Few states have proposed guidance levels for PFAS air emissions, while one state has a final promulgated rule. As of September 2023, New Hampshire is the only state with an enforceable rule for PFAS in air emissions (Interstate Technology Regulatory Council 2023a). The state has set ambient air levels (AAL) for one PFAS substance, PFOA and its' salts. The 24-hour average standard is 0.07 $\mu g/m^3$ and the annual average standard is 0.024 $\mu g/m^3$. Air pollutants are typically measured in micrograms per cubic meters ($\mu g/m^3$), but this measurement is equal to and commonly referred to as 1 part per billion (ppb).

Although New Hampshire is the only state with a final rule, other states have set health-based guidance levels for some PFAS chemicals. Michigan has set 24-hour average guidance levels for PFOA and PFOS at 0.07 $\mu g/m^3$ each, 1-hour average for perfluoroisobutylene (PFIB) at 0.8 $\mu g/m^3$, 8-hour average for perfluorobutylethylene (PFBE) at 10,000 $\mu g/m^3$, and an annual average for 6:2 fluorotelomer sulfonate (6:2 FTS) at 1.0 $\mu g/m^3$, PFBE at 2,600 $\mu g/m^3$, and perfluorobutylethylmethyldichlorosilane at 2.0 $\mu g/m^3$ (Interstate Technology Regulatory Council

2023a). Minnesota has developed Risk Assessment Advice (RAA) for many PFAS chemicals including guidance levels for exposure to a substance for 24 hours for greater than 30 days and greater than 8 years (24 hr., > 30 dy., > 8 yr.), for 24 hours (24 hr.), and for greater than 30 days and greater than 8 years (>30 dy. and > 8 yr.). Minnesota's RAA for 24 hr., >30 dy., >8 yr. is set for PFOA at 0.063 µg/m^3, PFOS at 0.011 µg/m^3, perfluorobutyric acid (PFBA) at 10 µg/m^3, PFBS at 0.3 µg/m^3, and PFHxS at 0.034 µg/m^3. Additionally, an RAA for perfluorohexanoic acid (PFHxA) for 24 hr. exposure is set to 1.0 µg/m^3 and >30 dy. and >8 yr. exposure for this substance set to 0.5 µg/m^3 (Interstate Technology Regulatory Council 2023a). New York has an Annual Guideline Concentration for PFOA in air set to 0.0053 µg/m^3 annual average (Interstate Technology Regulatory Council 2023a).

New Jersey has set reference concentrations for PFOA at 0.007 µg/m^3 and PFOS at 0.006 µg/m^3 and a screening reference concentration for HFPO-DA, GenX chemicals, at 0.01 µg/m^3 (Interstate Technology Regulatory Council 2023a). A reference concentration can be defined as an estimation of continuous human exposure through breathable air that will not cause detrimental effects to that person (EPA 2022). The difference between the reference concentration standard and screening reference concentration standard is that the "screening" level suggests there is more uncertainty with the numerical value (Post and Fang 2022). Texas has also set reference concentrations for several PFAS in air including PFOA at 0.0041 µg/m^3, PFOS at 0.081 µg/m^3, PFNA at 0.028 µg/m^3, PFBA at 3.5 µg/m^3, PFBS at 4.9 µg/m^3, PFHxS at 0.013 µg/m^3, PFOSA at 0.0041 µg/m^3, perfluorodecanoic acid (PFDA) at 0.053 µg/m^3, and perfluorododecanoic acid (PFDoDA) at 0.042 µg/m^3. Additionally, Texas has 1-hour average guidance levels set for PFOA at 0.05 µg/m^3 and PFOS at 0.1 µg/m^3 and annual averages for

PFOA at 0.005 µg/m^3 and PFOS at 0.01 µg/m^3 (Interstate Technology Regulatory Council 2023a).

Altogether, there is one state with a promogulated and enforceable standard for PFAS in ambient air and five other states with suggested health guidelines for PFAS in air. These standards and guidelines encompass only 15 PFAS. The delayed action in state air policy is most likely due to a perceived lesser threat to human health, as well as the difficulty in monitoring for these substances in ambient air. Groundwater and drinking water regulations are a direct threat to human health by bioaccumulation of these PFAS in the human body through ingestion of contaminated water. While airborne PFAS may also be inhaled through contaminated air, they can also be indirectly deposited in water systems or agricultural crops. However, this indirect consumption would occur at lesser amounts than if PFAS were directly introduced into groundwater by manufactured waste products. Additionally, the methods of collecting water samples for testing PFAS tend to be easily attained and more affordable than the technical sampling trains required in the air methods.

Soil Policies by State

Soil is another environmental media highly contaminated with PFAS across the nation. While the federal government has proposed regulations for listing PFOA and PFOS under CERCLA, which would provide guidance for clean-up of contaminated land, several states have already enacted policies concerning PFAS levels in soil. As of August 2023, there have been fourteen states who have taken some action against PFAS in soil by developing soil screening levels and/or standards for groundwater protection and surface water protection (Interstate Technology Regulatory Council 2023). Many of these states have only regulated for PFOA and PFOS including Alaska, Florida, Michigan, Nebraska, and New York (Interstate Technology

Regulatory Council 2023). Michigan was the first state to enact any type of policy regarding PFAS in soil when in 2016, the state created Groundwater Surface Water Protection Criteria for PFOA and PFOS. These levels were set to 10 mg/kg (ppm) for PFOA and 0.00024 mg/kg for PFOS in soils and sediments contained in drinking surface water and non-drinking surface water (Interstate Technology Regulatory Council 2023). Alaska was next in 2017 with producing clean-up levels for PFOA and PFOS in soils set at 0.0017 mg/kg and 0.003 mg/kg, respectively (Interstate Technology Regulatory Council 2023). In 2018, Nebraska set remediation goals for these substances in soil, with PFOA at 0.0006 mg/kg and PFOS at 0.00078 mg/kg (Interstate Technology Regulatory Council 2023). Florida followed with setting provisional soil clean-up target levels in 2019 for PFOA set to 0.002 mg/kg and PFOS set to 0.007 mg/kg (Interstate Technology Regulatory Council 2023). In 2020, New York set guidance values for PFOA and PFOS in soil at 0.0011 mg/kg and 0.0037 mg/kg, respectively (Interstate Technology Regulatory Council 2023). The other nine states that have developed standards for soil screening levels and/or standards for groundwater protection and surface water protection are Connecticut, Hawaii, Maine, Massachusetts, New Jersey, North Carolina, Pennsylvania, Texas, and Washington. Hawaii has set standards for the most substances at 18 PFAS, and Texas is second with standards for 16 PFAS (Interstate Technology Regulatory Council 2023).

In addition to setting standards for soil screening levels and/or standards for groundwater protection and surface water protection, states are also creating human health soil screening levels. As of August 2023, there are currently 22 states with these types of health-based guidance levels for PFAS in soils (Interstate Technology Regulatory Council 2023). At this level, few states have created screening levels for only PFOA and PFOS, including Alaska, Florida, Nebraska, and New York (Interstate Technology Regulatory Council 2023). The health-based standards overall have a higher screening recommendation throughout states. Alaska and Florida have clean-up levels set to 1.3 mg/kg for both PFOA and PFOS (Interstate Technology Regulatory Council 2023). Nebraska's health-based remediation goals are set to 0.32 mg/kg for PFOA and 3.2 mg/kg for PFOS (Interstate Technology Regulatory Council 2023). However, New York strays from this trend by having health-based guidance values lower than the soil screening levels with regards to groundwater protection. New York has the most stringent values for human health risk set to 0.00066 mg/kg for PFOA, and 0.00088 mg/kg for PFOS (Interstate Technology Regulatory Council 2023). The higher values seen at the health-based guidance levels, with the exception of New York, is most likely due to exposure route threatening human health. Direct ingestion of soil contaminated with PFAS is highly unlikely to cause health risks, but soils located near surface and groundwater sources have higher cause for concern when accumulating in water that people will directly ingest. The other fourteen states to have some sort of health-base guidance levels include Connecticut, Delaware, Hawaii, Indiana, Iowa, Maine, Massachusetts, Minnesota, Nevada, New Hampshire, New Jersey, New Mexico, North Carolina, Texas, Vermont, Washington, and Wisconsin (Interstate Technology Regulatory Council 2023). Hawaii has set health-based standards for the most substances at 18 PFAS, and Texas is in second with standards for 16 PFAS (Interstate Technology Regulatory Council 2023).

Various Adjacent State Policies

In addition to environmental policies concerning PFAS in water, air, and soil, many states have begun taking action against various consumer products and firefighting foams that contain these harmful substances. Food packaging is a major area of concern when protecting human health from the effects of PFAS. Many food wrappers and containers have a non-stick surface or covering that prevents grease leaks, all of which contain PFAS as the magical ingredient to deter the unwanted effects. States that are beginning to ban these uses of PFAS include California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nevada, New Hampshire, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington (Safer States 2023a). Some of these bans are already being enacted while others have a future date set for compliance.

AFFF is another product on the market that states are implanting policies against. PFAS have been added to these fire-fighting foams which are extremely effective at extinguishing fires at very high temperatures. As noted in Chapter 1, the military is the main user of this product for using these to put out actual fires, as well as for training exercises. These foams are also a great commodity at airports and other facilities with large amounts of solvents or fuels which could create a massive, intense heat fire. AFFF has been a culprit responsible for much of the environmental contamination in the United States, which have led states to enact policies against the use or distribution of these foams that include PFAS. States that have created bans against AFFF containing PFAS include California, Colorado, Connecticut, Hawaii, Illinois, Maine, Maryland, Minnesota, New Hampshire, Nevada, New York, Vermont, and Washington (Safer States 2023a). Additionally, Arizona, Kentucky, and Michigan have implemented a ban on the use of these foams for training purposes only (Safer States 2023a). In addition to the bans, several states have also initiated reporting requirements for releases of AFFF into the environment. Take-back programs have also been established in many states for foams containing AFFF.

The other categories of consumer products containing vast amounts of PFAS include textiles and cosmetics. Textiles containing PFAS include clothing, rugs and carpeting, and upholstered furniture, among others. States that have passed legislation banning PFAS from textiles include California, Colorado, Maine, Maryland, Minnesota, New York, Rhode Island, Vermont, and Washington (Safer States 2023a). Specific policies against the use of PFAS in firefighting clothing and equipment have been developed in California, Colorado, Indiana, Maryland, New York, Vermont, and Washington (Safer States 2023a). Various cosmetics incorporate PFAS in their formulas including lipstick and other lip products, foundations and concealers, and waterproof mascaras and other eye products (Green Science Policy Institute 2023). States that have PFAS policies pertaining to cosmetics include California, Colorado, Georgia, Hawaii, Illinois, Maryland, Minnesota, Nevada, New York, Rhode Island, Oregon, and Washington (Safer States 2023a). These policies include bans on intentionally adding PFAS to products, in addition to requiring companies to produce consumer product notifications.

As shown above, many states are developing policies to protect human health and the environment through direct environmental media policies including water, air, and soil, and through indirect hazards such as food packaging, firefighting foams, and consumer products. However, one area of environmental policy has not been as prevalent throughout states and that area is destruction and disposal of PFAS wastes. New York was the first to place a ban on incineration of AFFF containing PFAS (Esch 2020). This policy was signed by New York Governor Andrew Cuomo on November 23, 2020 (Esch 2020) in response to reported contamination of PFAS by the Norlite incinerator in Cohoes, New York. The ban was not statewide and only applied to incineration facilities in environmental justice areas. The policy was also limited to AFFF containing PFAS and not PFAS compounds contained in other materials or waste streams. Maryland also passed similar legislation banning incineration of AFFF containing PFAS. Illinois is the only state to place a ban on incineration of PFAS listed on the TRI. The Illinois legislation is unique since it banned more than just AFFF incineration. Further analysis is given in Chapter 3 on the Illinois legislation.

Hazardous Designation Listing

Hazardous waste designation has yet to be made for any single PFAS. As mentioned in Chapter 1, hazardous chemicals can be listed under either RCRA or CERCLA. Petitions to the EPA to classify these chemicals as such have come from numerous sources, including but not limited to University of California, Berkeley and the Public Employees for Environmental Responsibility (Lujan Grisham 2021). However, in 2021 when the EPA received a petition from New Mexico Governor Michelle Lujan Grisham, there was an honest response to take action given by the administration. The petition was sent on June 23, 2021, and urged the EPA to designate PFAS as a class or individually listed as hazardous substances under RCRA (Lujan Grisham 2021). Governor Lujan Grisham noted the widespread contamination throughout her state, specifically areas in the vicinity of the state's two air force bases. There was documented contamination in nearby dairy farms and lakes, which ultimately would affect her state's human health initiatives, agricultural industries, recreation and tourism (Lujan Grisham 2021). Furthermore, she pleaded with the administration that federal action was required expediently as not to leave the state trying to apply protections against these chemicals that may not be sufficient enough.

EPA Administrator Michael Regan responded to Governor Lujan Grisham on October 26, 2021, shortly after the release of the EPA's PFAS Strategic Roadmap action plan on October 18, 2021 (Regan 2021). In his response, Administrator Regan proceeded to agree with the arguments made by the New Mexico governor and made assurances that the EPA would begin to take action on addressing PFAS as hazardous chemicals. However, contrary to Lujan Grisham's request, the EPA planned to only designate certain individual chemicals rather than the group as a class, which would have provided protections against the thousands of PFAS in commerce (Regan 2021). Administrator Regan explained that the PFAS to be listed as hazardous constituents included PFOA, PFOS, PFBS, and HFPO-DA (GenX chemicals). The plan was to review available research on these chemicals to provide reasoning for the listing, and they would then be added to RCRA 40 CFR Part 261 Appendix VIII (Listed Hazardous Wastes) (Regan 2021). Furthermore, it was acknowledged in the response that when the listing of these four PFAS as hazardous is finalized, they would be included in the RCRA Corrective Action plan which would require manufacturers and generators of these materials to investigate and clean-up contaminated media for which they are liable.

In response to the petitions and as part of the PFAS Strategic Roadmap, the EPA did take action to list PFAS as hazardous substances. On September 6, 2022, a proposed rulemaking was published in the Federal Register under CERCLA to designate PFOA and PFOS, including their salts and isomers, as hazardous substances (EPA 2023c). Linear and branched isomers of PFOA and PFOS must contain the eight perfluorocarbon atoms and carboxylic acid and sulfonic acid functional groups, respectively, but can contain different arrangements of these carbon atoms in the chain structure. There was a sixty-day timeframe granted for the comment period on the proposed rule, ending comments on November 7, 2023 (EPA 2023c). After this deadline, the EPA planned to review feedback given on the rule by the general public and stakeholders, with a target date for a finalized rule to be released in August 2023 (EPA 2023c). This finalized regulation has yet to be established. As noted in the EPA's Spring 2023 Unified Agenda, the rule has been delayed and set to release in February 2024 (Office of Information and Regulatory Affairs 2023).

There are a few considerations to acknowledge for the proposed rule. Contrary to the response given by EPA Administrator Michael Regan, only PFOA and PFOS were proposed for hazardous designations and not PFBS and HFPO-DA. This is strongly due to the availability of health toxicity information for PFOA and PFOS as compared to available research on PFBS and HFPO-DA. There is significant evidence available that shows these two compounds pose a serious threat to human health and welfare (EPA 2023c). The EPA did release an Advanced Notice of Proposed Rulemaking (ANPRM) requesting public and stakeholder feedback on listing additional PFAS as hazardous substances under CERCLA (Federal Register 2023). The comment period was to end in sixty days as standard, but the comment period was extended to August 11, 2023 due to numerous requests from interested parties (Federal Register 2023a). This ANPRM was requesting feedback for seven PFAS, along with their salts and isomers, including PFBS, PFHxS, PFNA, HFPO-DA, PFBA, PFHxA, and PFDA (Federal Register 2023). Additionally, the ANPRM asked for comments pertaining to hazardous designation of precursors to PFOA, PFOS, and the seven PFAS listed above, and classifying categories of PFAS as hazardous substances (Federal Register 2023).

The other topic for consideration is the fact that PFOA and PFOS were proposed as hazardous substances under CERCLA, and not RCRA, as requested by Governor Michelle Lujan Grisham and acknowledged by Administrator Michael Regan. When the finalized designation is made and posted to the Federal Register, this will require entities that manufacture, process, or otherwise use PFOA and PFOS to report releases and will also hold parties liable to future contamination of these compounds, as well as legacy contamination issues. Releases to air, water, or land of PFOA and PFOS will be required immediately if in exceedance of the Reportable Quantity (RQ) (EPA 2022a). RQs are assigned to CERCLA hazardous substances with a standard of one pound (lb.) unless the EPA revises the RQ under statutory rule (EPA 2022a). Reporting requirements will assist local, state, and federal government agencies in assessing the location and extent of releases of PFOA and PFOS. This rule will also allow for expedient agency response to clean-up efforts of PFOA and PFOS, as compared to the current practice which involves CERCLA statutes regarding pollutants and contaminants. PFOA and PFOS can qualify as pollutants or contaminants under CERCLA, which grants authorities to order clean-up of sites contaminated with these substances. However, in order to do so, the agency needs to provide evidence that the contamination is an imminent and substantial danger, which undeniably prolongs the process (EPA 2022a). Finally, the rule will give national consistency on clean-up efforts for PFOA and PFOS (EPA 2022a).

As mentioned in Chapter 1, the designation of PFOA and PFOS under CERCLA does not grant adoption of these chemicals as PFAS hazardous wastes under RCRA. In this manner, the CERCLA designation does not provide as much protection as would have been under a regulatory statute such as RCRA. There is still anticipation for a proposed rulemaking to designate the four original compounds- PFOA, PFOS, PFBS, and HFPO-DA, under RCRA as acknowledged in Michael Regan's response to the New Mexico Governor's petition. However, there has not been any proposal to date posted in the Federal Register to commence a public comment period for this regulatory action. Although reporting and clean-up efforts will begin under the CERCLA hazardous designation, there will continue to be future contamination if PFAS are not managed from cradle-to-grave. End-of-life disposal remains unregulated for these substances and will continue to create risk to public health and the environment until statutory regulations are developed under RCRA.

PFAS Disposal- Incineration

While there is no comprehensive research or regulatory standard, the US EPA has issued guidance on end-of-life processes for per- and polyfluoroalkyl substances. The first interim guidance for disposal and destruction of PFAS was published for public comment on December

18, 2020 (EPA 2020). The technologies discussed in this guidance include thermal treatment (incineration), landfilling, and underground injection control. PFAS destruction can be defined as completely severing all carbon-fluorine bonds on the chemical (EPA 2020). The only true destruction technology included in the EPA's 2020 guidance is thermal treatment, or incineration. There are different types of thermal treatment technologies including hazardous waste combustors, carbon reactivation units, non-hazardous waste combustors, and thermal oxidizers (EPA 2020). The guidance explains that hazardous waste incineration "can potentially achieve temperatures and residence times sufficient to break apart the PFAS contained in the waste stream being thermally treated (EPA 2020)." These incineration facilities are highly regulated with specific standards that need to be met, including a 99.99% destruction efficiency.

Incineration of PFAS has not been significantly researched on an industrial level in the United States. Currently, hazardous waste incineration is the preferred technology for most halogen destruction, including chlorine, bromine, polychlorinated biphenyls (PCBs), chlorofluorocarbons, and hydrofluorocarbons, so it would be reasonable to surmise that this would be preferably for PFAS as well. However, the carbon-fluorine bond is 1.5 times stronger than the carbon-chlorine bond, which means the highly fluorinated PFAS may require higher temperatures and longer residence times to completely break down (EPA 2020). The main concern with incineration is the ability to entirely destroy PFAS, with fear that there may be creation of products of incomplete combustion (PICs) and possible formation of other PFAS (Gullett and Gillespie 2020). Air emissions of these compounds and how they transform through the incineration process is also not well-understood.

Combustion technology burns waste streams with the presence of oxygen (Wang et. Al. 2022). In complete combustion of PFAS, byproducts would be similar to that of other hydrocarbon compounds including cardon dioxide and heat and light, with the addition of hydrofluoric acid (HF). See the figure below that depicts a generalized PFAS combustion reaction. Temperature, gas mixture, waste components, gas turbulence, and residence times are the main factors driving complete combustion in incineration units (Wang et. al. 2022). Depending on the waste stream to be treated, these factors can be adjusted to the right setting to destroy the waste and avoid creation of unwanted byproducts.

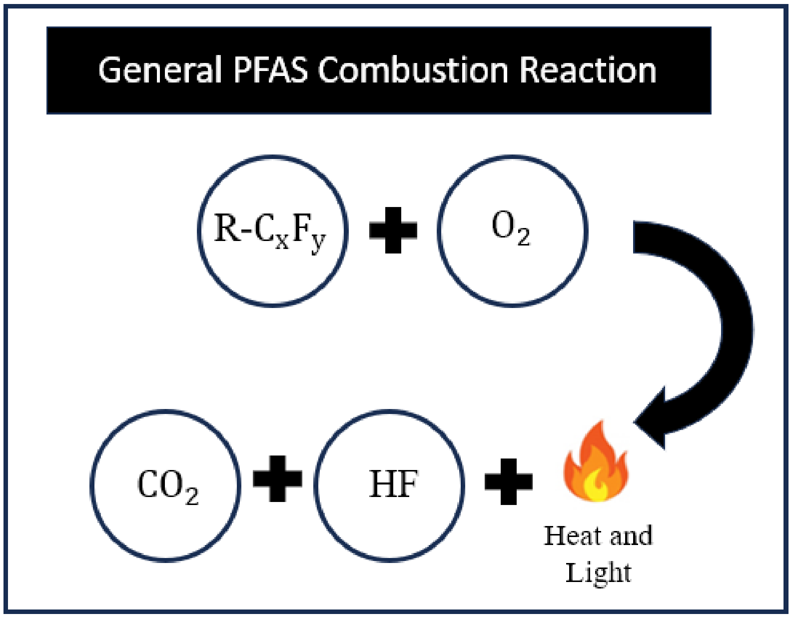


Figure 4: Generalized combustion reaction for PFAS

Carbon tetrafluoride (CF_4) is the most stable fluorinated carbon compound and requires temperatures over 2550°F to completely destroy (Gullett and Gillespie 2020). In many PFAS chemicals, there exists carbon-carbon bonds, possible carbon-hydrogen bonds in the polyfluoroalkyl variety, and a range of functional groups. Through incineration, there is an unknown associated of where the bonds will break on the PFAS molecules. There is a possibility of not all carbon-fluorine bonds breaking which could result in PICs of smaller, distinguishable

PFAS or other fluorinated compounds. This is an area that needs further research to determine the exact operating parameters to avoid these unwanted PICs. It is noted in EPA's guidance that sufficient temperatures and high concentrations of hydrogen radicals (often found in flames) will produce the right environment to completely degrade all carbon-fluorine bonds (EPA 2020).

Hazardous waste incinerators are typically designed with a two-chamber plan including a primary combustion unit (often a rotary kiln) and secondary combustion unit (Cao et. al. 2018). See Figure 5 below for a general layout of these systems. These incinerators run at high average temperatures and have the best potential for complete destruction of PFAS. Municipal waste combustors (MWC) have low temperatures, and sewage sludge incinerators (SSI) employ even lower temperatures. Carbon reactivation systems have been shown to effectively remove PFAS from carbon media with little-to-no release to the environment in bench scale studies, but this technology is limited in the waste streams (only carbon) that can go through the process (EPA 2020). Thermal oxidizers are also being analyzed to determine if this technology can destroy PFAS; although, their function is not typically for destruction, rather control, of site-specific liquid and gaseous streams (EPA 2020).

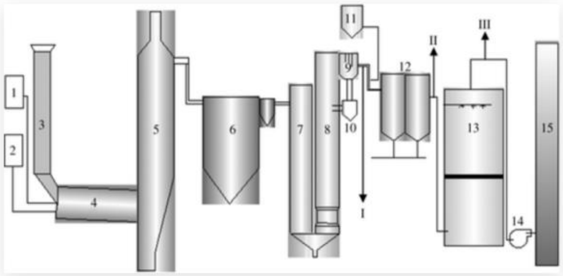


Figure 1. Schematic diagram and sampling sites of the investigated HWIs: (1) hazardous wastes; (2) air; (3) feeder; (4) rotary kiln; (5) secondary combustion chamber (outlet temperature: 1000–1100°C); (6) boiler (outlet temperature: 500–600°C); (7) quenching tower; (8) neutralization tower; (9) lime recycle device; (10) lime chamber; (11) activated carbon chamber; (12) bag filter; (13) wet scrubber; (14) fan; (15) stack. Sampling points: (I) quenching tower outlet (200–250°C); (II) bag filter outlet (180–220°C); (III) wet scrubber outlet (100–125°C).

Figure 5: Hazardous waste incinerator design (Cao et. al. 2018)

Public concern with incineration is often generated by the idea of toxic gas emissions spewing into surrounding communities (Wang et. al. 2015). The production of HF as an airborne byproduct does create concern for the incineration of PFAS, since HF is a regulated hazardous air pollutant (HAP) under the CAA. In addition to HF, gaseous PFCs could potentially be emitted if incomplete combustion of PFAS were to occur (Wang et. al. 2015). However, hazardous waste incinerators are equipped with pollution control technologies, typically wet or dry scrubbing systems, to deter some of the unwanted acid gases. In these wet or dry scrubbers, low-cost calcium compounds are used to mineralize these toxic substances into non-hazardous materials that will ultimately be sent to landfill (Wang et. al. 2015).

In a study conducted by Wang et. al. in 2015, this method was tested to determine effectiveness of mineralizing PFAS with calcium compounds. Different PFAS were researched including PFOS, PFOA, PFHxS, PFOSA, and PTFE. The calcium compounds used to mineralize the PFAS were calcium hydroxide ($Ca(OH)_2$), calcium carbonate ($CaCO_3$), and calcium oxide (CaO), commonly known as lime. This study showed that the calcium compounds were effective in mineralizing the above PFAS. Interestingly, it was discovered that carbon chain length did not have much effect on the mineralization behavior, while the functional group affected this greatly (Wang et. al. 2015).

In the study mentioned above, it was determined that PFAS containing the sulfonate functional groups were mineralized very efficiently, while the PFAS containing the carboxylate and sulfonamide groups may require additional or different treatment to effectively remove all risk of toxic emissions (Wang et. al. 2015). The fluoropolymer, PTFE, showed significant success with mineralization when introduced to $Ca(OH)_2$. The increase in temperature during the experiment also heightened the mineralization efficiency (Wang et. al. 2015). It is important to note that this was a bench-scale experiment and may have different outcomes on an industrial scale, but these results are significant and should be researched further.

Besides concern for toxic emissions, the other undetermined factor in PFAS incineration is the products of incomplete combustion that could potentially be formed during the incineration process. A test trial for incineration of PFAS-contaminated soils began in 2018 at US Ecology's Moose Creek Facility located in North Pole, Alaska (NRC Alaska 2019). The facility completed this testing "to evaluate operating capacities, establish operational procedures, and quantify air emissions" of PFAS (NRC Alaska 2019). With this test trial, Moose Creek planned to use their data results for remediation of PFAS to include in their permit application that was to be submitted to the Alaska Department of Environmental Conservation (ADEC) in order to show compliance with regulatory requirements for thermal treatment. This permit application was approved in April 2019, and the facility was fully enabled to incinerate PFAS-contaminated soils in May of 2019. The granted permit came at the same time that Moose Creek was due for an air emission source test, and the facility was able to collect further data in regards to PFAS incineration (NRC Alaska 2019).

Moose Creek operates a 17 million British Thermal Unit per hour (BTU/hr.) refractory-lined rotary kiln primary combustion unit equipped with a secondary combustion unit in which gases from the primary chamber are routed (NRC Alaska 2019). The secondary chamber is also refractory-lined and is an 8 million BTU/hr. unit. After gases leave the secondary combustion unit, they go into a cool-down chamber before entering a baghouse system. When leaving the baghouse system, gases exit through the incinerator's 60-foot-tall stack and are introduced into the surrounding air (NRC Alaska 2019). This was the exact process for waste streams during the

2018 test trial, but shortly after this was conducted, a wet scrubber system was installed after the baghouse filtration (NRC Alaska 2019).

The Moose Creek facility is located one mile from the Eielson Air Force Base (EAFB), and they received 89.7 tons of PFAS contaminated soil from EAFB to conduct their test trial in 2018 (NRC Alaska 2019). The facility analyzes incoming soil waste streams and determines operating parameters “based on the soil characteristics, moisture content, level of contamination, and ambient conditions (NRC Alaska 2019).” In the 2018 test trial, different trial runs were conducted with a range of temperatures, kiln ranging from 800°F to 1500°F and secondary combustion chamber ranging from 1800°F to 2200°F, and feed rates 1 ton per hour to 6 tons per hour (NRC Alaska 2019). 24 per- and polyfluoroalkyl substances were analyzed at SGS laboratories utilizing method 537M, a method originally developed for drinking water that has the ability to efficiently detect PFAS through liquid chromatography and a tandem mass spectrometry (Shoemaker and Tettenhorst 2020).

From the 2018 test trial, 28 samples from the pretreatment soil established that PFOS and PFOA were in all the samples at levels higher than the ADEC target cleanup levels (CULs), along with 19 other PFAS (NRC Alaska 2019). ADEC CULs set at this time were 0.0030 ppm for PFOS and 0.0017 ppm for PFOA. There were 18 soil samples taken from the post-incineration soil piles and 8 samples taken from post-incineration soil piles that included baghouse fines to analyze final PFAS concentrations (NRC Alaska 2019). All PFAS were considered non-detectable in the post-incineration samples, with the exception of PFOS being found in 9 samples at levels less than the ADEC CULs and PFHxS detected at very low concentrations of two samples that included baghouse fines (NRC Alaska 2019). It was later determined that the cool down chamber water was contaminated with low levels of PFAS that could have possibly interfered with the data; however, this was not accounted for in the final collection numbers (NRC Alaska 2019).

Air emissions testing was also conducted during the 2018 test trial at the Moose Creek facility utilizing Alaska Source Testing, LLC. This test investigated the same 24 PFAS that were looked at in the soil samples, also using SGS laboratories and method 537M (NRC Alaska 2019). XAD traps, tubes commonly used to capture samples at emission sources, were used to capture samples from the stack. 11 PFAS compounds were detected in the air samples, including perfluorotetradecanoic acid (PFTA) which was not originally detected in the pretreatment soil samples (NRC Alaska 2019). Combining all 11 PFAS, an overall average emission rate was determined to be 0.0791 mg/hr. in the facility's stack. With this trial, there was the same contamination from the cool down chamber water that could have interfered with the data results. There was also another potential interference of the XAD traps themselves containing low levels of PFAS (NRC Alaska 2019).

Based on the 2018 test trial at Moose Creek, this incineration process was effective at removing PFAS from the contaminated soil waste streams, but did have low level air emissions of 11 of these compounds (NRC Alaska 2019). The incineration of PFAS did also produce emissions of HF, fluorine, sulfur dioxide, and carbon dioxide. HF was emitted from the stack at 0.0048 lbs./hr., and fluorine was emitted at 0.252 lbs./hr. Due to the combined emissions, ADEC made a recommendation to install the wet scrubber system to help control acidic emissions and possibly aid in reducing PFAS emissions (NRC Alaska 2019), which the facility did have installed before the 2019 air compliance testing.

In 2019, Moose Creek conducted their air compliance testing for their ADEC-approved Air Quality Control Minor Permit. During this emissions test, the facility also analyzed pre- and post-treatment soil samples. Again, the facility received the contaminated soil from the EAFB, who confirmed the soil did contain levels above the CULs for PFOS at concentrations between 0.000640 ppm and 0.010 ppm (NRC Alaska 2019). In late 2018, the ADEC proposed new CULs for six PFAS. This lowered CULs for PFOA to 0.00029 ppm and PFOS to 0.00053 ppm (NRC Alaska 2019). The procedure was the same as the 2018 trial with varying temperatures and feed rates within the same ranges. Only 6 PFAS were tested in this trial, and were non-detect for all compounds except PFOS in the pre-treatment samples. In the post-treatment samples, PFOS was detected in 2 of the 4 samples collected but were at much lower levels than the pre-treated soil, with concentrations at 0.00023 ppm and 0.00028 ppm (NRC Alaska 2019). The 5 other PFAS were not detected in the post-treated soil.

For the air compliance test in 2019, Alaska Source Testing, LLC conducted the trial with samples sent to Eurofins TestAmerica for laboratory analysis (NRC Alaska 2019). The same 24 PFAS were analyzed in the 2019 air emissions inspection. Of the 24 compounds, 11 were found to be non-detectable in the air samples (NRC Alaska 2019). PFOA had the highest emission rate of 0.0436 mg/hour, and the remaining compounds were also found to be emitted at small amounts. There was an issue with contamination during this appraisal as well- XAD traps and water for cool down and wet scrubber. The installation of the wet scrubbing system at the facility effectively reduced fluorine emissions by 94.6% and HF emissions by 93.5% when compared to the 2018 trial (NRC Alaska 2019).

Overall, it was determined that if the facility operates 24 hours a day, 7 days a week, 365 days a year, the total potential-to-emit (PTE) PFAS emissions would be 0.24 lbs./yr. based on the 2018 test and 0.26 lbs./yr. based on the 2019 test (NRC Alaska 2019). This 5 percent increase in PFAS emissions can potentially be explained by developing laboratory techniques that can detect these compounds with higher sensitivity than previously available (NRC Alaska 2019). Based on the conclusion of this study, incineration seems to be a viable end-of-life technology to destroy PFAS.

PFAS Disposal- Landfill and Underground Injection Control

In addition to incineration, landfilling is another option for PFAS disposal. Landfilling operations are not a viable solution for destruction of PFAS but rather serve as a long-term disposal option. There are different types of landfills in the United States, which are regulated under the RCRA. The types of landfills include those regulated under Subtitle D of RCRA- Municipal Solid Waste Landfills and Industrial Waste Landfills- and under Subtitle C of RCRA- Hazardous Waste Landfills. Subtitle C landfills, for hazardous wastes, do have many controls in place that would probably best serve PFAS disposal in order to prevent their leaching into the environment (EPA 2020). Currently, PFAS are able to enter any type of landfill- Subtitle D (solid waste) including municipal solid waste and industrial waste or Subtitle C (hazardous waste), and at any concentration. This causes concern for possible landfill leachate material and landfill gases that could include PFAS.

Landfill leachate is defined as the liquid that accumulates from landfills due to rainfall that moves through the buried waste and draws out chemicals or constituents contained in the waste (EPA 2023d). Highly contaminated landfill leachate can negatively affect the environment by seepage out of the landfill into nearby soil and groundwater sources and volatilization of certain chemical compounds contained in the substance which then enters the atmosphere. Although liners are generally in place at all landfills, runoff and seepage can still occur. Studies conducted in Michigan, Minnesota, and Vermont have all documented PFAS contamination in groundwater sources near current or closed landfill facilities (Stoiber et. al. 2020). Collection of landfill leachate occurs at most currently operated landfills, which is then treated at wastewater treatment plants (WWTP). However, especially in the case of PFAS, these chemicals can pass through the system unaffected since they are unregulated and their management is not required. The general practices used at WWTPs do not have the capabilities to treat for PFAS in the water (EPA 2020).

There has been some research into the presence of PFAS in landfill leachate. A study conducted on 18 landfills in the United States in 2017 revealed that untreated leachate analyzed for 70 PFAS found concentrations totaling up to 66 µg/L or ppb (Stoiber et. al. 2020). A separate study conducted in 2020 on 5 landfills in the United States and testing for 11 PFAS showed results totaling up to 18 µg/L or ppb (Stoiber et. al. 2020). These values may seem insignificant but when compared to the proposed MCLs for PFOA and PFOS in drinking water at 4 ppt (or 0.004 ppb), their magnitude is easier to comprehend. The 2020 research conducted by Solo-Gabriele et. al. provided a further analysis on types of landfills and PFAS concentrations including municipal solid waste, construction and demolition (type of industrial waste), and ash landfills, which receives chiefly incinerator ash residuals. Lower levels of PFAS were detected in ash landfills, while municipal solid waste and construction and demolition landfills has similar values (Solo-Gabriele et. al. 2020). Furthermore, there was some documented correlation between a decreased PFAS concentration in landfill leachate and the temperature at which the incineration process ran at to produce the ash; however, more research is needed to study this relationship further (Solo-Gabriele et. al. 2020).

Landfill gases are formed through the natural “decomposition of organic materials in landfills” (EPA 2023h). Landfill gas is composed of approximately 50% methane, 50% carbon dioxide, and a small mixture of other chemicals contained in the landfill waste which volatized

(EPA 2023h). Research has been done on the amount of PFAS in landfill gases in Canada, China, and Germany (Stoiber et. al. 2020). The air above landfills was tested for these chemicals and resulted in 22 PFAS tested for at 2 landfills in Canada and totaling up to 26 ng/m^3 in 2011, 30 PFAS tested for at 2 landfills in Germany and totaling up to 0.7 ng/m^3 in 2011, 23 PFAS tested for at 2 landfills in China and totaling up to 9.5 ng/m^3 in 2018, and 29 PFAS tested for at 3 landfills in China and totaling up to 33 ng/m^3 in 2020 (Stoiber et. al. 2020). These results give evidence that landfill gases are a direct contributor to PFAS in atmospheric pollution (Stoiber et. al. 2020).

Underground Injection Control (UIC), also known as Deep-Well Injection, is also a disposal, not destruction, option for PFAS but is limited to only liquid wastes (EPA 2020). Class I wells for underground injection are divided into categories based on the material accepted, which can include municipal wastewater, radioactive waste, hazardous waste, and non-hazardous industrial waste (EPA 2020). These liquids are administered into geological formations deeper than the lowest underground source of drinking water, typically between 1,700 to over 10,000 feet deep (EPA 2020). The zones, at which wastes are injected into, are permeable layers able to hold and absorb the liquids and are separated vertically from underground water sources by at least one layer of impermeable rock (EPA 2020). Underground injection control for PFAS wastes is confirmed to be taking place at two sites in the United States: Michigan has a non-hazardous industrial waste Class I well accepting PFAS material, and Texas has a hazardous waste Class I well accepting PFAS materials (EPA 2020). Although there are some uncertainties with the practice, the EPA has determined there is minimal risk for environmental contamination through injecting wastes deep into the earth's geology. There are little to no air toxic air emissions resulting from the practice, and the design of these wells prevents wastes from infiltrating underground water resources (EPA 2020).

There has been little to no research on the impact of managing liquid PFAS waste streams in deep well injections. There are a few concerns regarding the feasibility of using underground injection control to manage the volume of PFAS wastes in the United States. First, this disposal technology is limited to only liquid wastes that must exhibit a low number of suspended solids. Additionally, these wastes must be compatible with other waste streams previously injected into these wells. Capacity is another factor since the United States currently has 823 deep-well injection facilities, in which only 53% are permitted for non-hazardous industrial waste disposal and 18% are permitted for hazardous waste disposal (EPA 2020). Since PFAS are not currently regulated as hazardous constituents, they are able to enter both of these types of injection wells. However, with the pending rulemaking to list at least PFOA and PFOS as hazardous, this presents very limited options on the locations and capacities at which these liquid waste streams can be accepted at UIC sites. Furthermore, for more facilities to accept PFAS-containing wastes, there would be a requirement for extensive permitting modifications due to increased waste volumes and changes in waste materials accepted, which may deter additional sites from wanting to accept these waste streams (EPA 2020).

The EPA’s interim guidance document released in December of 2020 attempts to provide disposal and destruction technology for non-consumer products based on the best available research at the time of its’ release. The EPA plans to update this document in December of 2023 due to further research initiatives providing more information on safe disposal practices of these chemicals. While PFAS wastes continue to be unregulated, the safe destruction and disposal of these materials is on stand-by. As noted, PFAS wastes are currently being stored in place awaiting further guidance or incinerated, landfilled, or injected underground without specific standards to ensure further environmental contamination is prevented.

CHAPTER III

RESEARCH OBJECTIVES, METHODOLOGY, AND RESULTS

This research project examines several areas of PFAS policy. To start, a micro-analysis of an Illinois PFAS policy that prohibits incineration is examined to determine the driving political and economic factors that led to its adoption. Since the Illinois case study is an internal narrative with little to no scientific justification, a macro-analysis is performed to elucidate the motivation for PFAS water policy appropriation among the fifty states and District of Columbia. Moving from state to federal legislation, the newly proposed PFAS NPDWR under the SDWA is dissected to explain the introduction of PFAS policy at the federal level. Finally, the US EPA's PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024 will be analyzed to determine the federal government's progress in protecting human health and the environment from these harmful contaminants. Upon completion of this study, there is a prescriptive discussion presented to recognize the new creation of PFAS policy across the United States.

Micro-Analysis of Illinois PFAS Incineration Ban

Illinois House Bill 4818 (HB 4818) passed both the House of Representatives and Senate on April 7, 2022. The bill was sent to Illinois Governor Pritzker on April 20, 2022 and signed into action by the Governor on June 8, 2022 (Illinois General Assembly 2022). This legislation prohibits the incineration of PFAS in the state of Illinois. This is a unique policy compared to the federal government and many other state governments, who all lack such a policy, but before analysis it should be noted this was not the first introduced policy of this kind in the state of Illinois. This can be perceived by the general public as a carefully planned and calculated policy, but for many academic and administrative professionals it was passed premature to any real scientific research being conducted on end-of-life destruction technology for PFAS. This research takes an in-depth examination in the following section at the process that occurred to pass HB 4818 in Illinois. Previous Illinois legislation, HB 3190, is investigated to describe why the failure to pass this very similar policy transpired. Publicly available documents from the Illinois General Assembly are reviewed to describe how this outcome was achieved. Additionally, insider knowledge and local environmental advocacy group work is examined to determine how the new HB 4818 emerged and was successfully passed in Illinois.

It is difficult to determine what exactly prompted PFAS incineration legislation is Illinois. The emergence of PFAS issues to the general public started to happen when people became aware of contamination and possible toxic or hazardous properties of this group of chemicals. A popular movie, Dark Waters, came out to the masses in 2019 which outlined the true events of PFAS contamination by DuPont in rural West Virginia (Mondor 2021). In addition, many lawsuits have been filed against manufacturers of PFAS when the pollution of waterways by these companies came into the public view. Two of the major sites include Cape Fear in North Carolina, polluted by Chemours, and the Twin Cities Metropolitan Area in Minnesota, polluted by 3M. The United States military and DOD have also been in focus in regards to PFAS contamination. Due to the extensive use of AFFF in training exercises and fire-fighting measures, the military is responsible for vast areas of contaminated land and water.

So, why is this PFAS incineration ban statuary proposed in Illinois and not in other states with a more publicly-focused contaminated area? Illinois is home to one hazardous waste incinerator, while other states contain many (EPA 2023). Ohio is home to four hazardous waste incinerators, and Texas, Missouri, and Arkansas all contain three separate facilities with these units (EPA 2023). If incinerating PFAS does not destroy these chemicals and poses a huge potential health risk, why not ban this practice nationwide or in a more incinerator-concentrated state, such as Ohio? Between 2018 and 2020, the US DOD contracted several incineration facilities to burn the stockpiles of AFFF they had accumulated (Fitzgerald 2020). Yes, one of the contracted incinerators was located in Ohio, but the lone incinerator in Illinois was also authorized to burn this waste. At first glance, my assessment is that Ohio is a Republican majority ruled state which is more friendly to industry in general, especially the hazardous waste industry. The case is not the same in the Democratic state of Illinois. Ohio is used in this context as one example to compare to Illinois, but other incineration facilities throughout the nation were also contracted to accept PFAS waste from the US DOD and have not banned incineration of these chemicals (Fitzgerald 2022).

Politics definitely have a role in the Illinois PFAS incineration legislation. However, the local area in the Metro East of St. Louis, specifically Sauget, Illinois and surrounding areas, are very outspoken against the environmental injustices their communities face. Sauget, IL is the location of the only hazardous waste incinerator in the state and belongs to Veolia, an environmental services and solutions company based out of France. Besides the hazardous waste incineration facility, Sauget is an industrial park containing numerous chemical companies and a couple of Superfund Sites under remediation. It must also be noted that surrounding towns of Cahokia Heights and East St. Louis are predominantly poor, non-white, marginalized communities. The announcement of authorization by the US DOD for Veolia to incinerate the AFFF containing PFAS waste could have sparked opposition by the local environmental groups, igniting the local need for a ban on PFAS incineration.

On February 19, 2021, Illinois State Representative, Ann Williams, democratic-Springfield, filed house bill 3190 (HB 3190). Shortly after filing, Illinois State Representative Latoya Greenwood, democratic- East St. Louis, became the chief sponsor of the bill (Illinois General Assembly 2021). In the first part of this policy, “incineration” and “perfluoroalkyl and polyfluoroalkyl substances" are defined. "Incineration includes, but is not limited to, burning, combustion, pyrolysis, gasification, thermal oxidation, (including flameless and regenerative), acid recovery furnace or oxidizer, ore roaster, cement kiln, lightweight aggregate, kiln, industrial furnace, boiler, and process heater, and Perfluoroalkyl and polyfluoroalkyl substances means a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom (Illinois General Assembly 2021)." Industry groups had issues with both definitions outlined in this bill, and as will be mentioned later, Governor Pritzker also had an issue with the incineration definition in the bill.

Industry groups, including the Illinois Manufacturer's Association (IMA) and Chemical Industry Council of Illinois (CICI), both took stances against this bill on behalf of their industry members largely in part for how these two categories were defined. Thermal oxidation was the main problem for manufacturers in the incineration language. Thermal oxidizers are used in the manufacture of PFAS to capture these, along with many other, emissions produced during the process. The issue that industry groups had with the PFAS definition was that it was too overly broad. Trying to determine a list of compounds that contained at least one fully fluorinated carbon atom would take extensive amounts of time to research and regulate.

The definitions remained consistent throughout the amendment process of this bill. As first introduced, HB 3190 read, "The disposal by incineration of aqueous film-forming foam that contains perfluoroalkyl and polyfluoroalkyl substances is prohibited in an area of environmental justice concern (Illinois General Assembly 2021)." This first version of the bill was very specific in the waste type, being only AFFF containing PFAS. It was also specific to certain areas in the state including only those of environmental justice concern. A house amendment was added to the bill that banned the incineration of AFFF containing PFAS throughout the whole state of

Illinois (Illinois General Assembly 2021). The final amendment to this bill switched the meaning quite drastically. Instead of aqueous film-forming foam containing per- and polyfluoroalkyl substances, this change implemented the ban on incineration of any PFAS, including but not limited to AFFF (Illinois General Assembly 2021). All amendments took place in the Illinois House of Representatives. This final version of HB 3190 was approved by the house and transferred to the Senate where it was also approved without change.

HB 3190 was sent to Governor Pritzker on June 25, 2021. However, the Governor issued a veto of the bill due to the definition of incineration. He noted that including thermal oxidation in the definition of incineration would cause an increase of greenhouse gas emissions, fluorides, hazardous air pollutants, volatile organic materials, and carbon monoxide at chemical manufacturing companies (Illinois General Assembly 2021). Although Governor Pritzker did favor the meaning behind the bill, he felt that drastically changing the definition of incineration exceeded his amendatory veto powers provided by the Illinois Constitution (Illinois General Assembly 2021). This was an interesting step in the policy process, as the veto given by the governor basically gave instructions on how to change the bill in order to pass in the next Illinois General Assembly session.

This first house bill on PFAS incineration introduced into Illinois legislation gives a good example of policy formulation. The policy evolved as it spent time in the House of Representatives and would continue to be formulated in future legislation. During this policy formulation stage, policy legitimation was also taking place. Advocates for this bill included a local environmental group, the United Congregations of the Metro East, and the Sierra Club. Before this bill had even passed both houses, the United Congregations of Metro East hosted an awareness event in Sauget, IL in April 2021 to celebrate Earth Day while also informing the community of the risks associated with burning PFAS (Schmid 2021). Cheryl Sommer, the President of the United Congregations of Metro East, is actually quoted at this event saying that money needs to be invested in developing a safe disposal option for PFAS and that incineration is not an option (Schmid 2021).

As mentioned at the beginning of this Chapter, the second legislation involving the ban of PFAS incineration was more successful than the first. HB 4818 was introduced, again by Illinois State Representative Latoya Greenwood, on January 25, 2022. However, the development of this bill was unlike than the first. Much of the policy formulation took place prior to introducing the bill into the legislature. Industry groups, along with environmental groups, were both able to add input on the language of the newly proposed bill. Veolia, the main company affected by this legislation, was actually able to discuss their concerns over the broad definition of per- and polyfluoroalkyl substances with Representative Greenwood before she introduced HB 4818.

In the introduction of the bill, the original language for definitions of both incineration and PFAS were adjusted from HB 3190. The new definitions in HB 4818 are as follows: “"*Incineration*" includes, but is not limited to, burning, combustion, pyrolysis, gasification, or the use of an acid recovery furnace or oxidizer, ore roaster, cement kiln, lightweight aggregate kiln, industrial furnace, boiler, or process heater, but does not include thermal oxidizers when they are operated as a pollution control or resource recovery device at a facility that is using PFAS chemicals. "*Perfluoroalkyl and polyfluoroalkyl substances*" or "PFAS" means a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom the list of PFAS defined in the US EPA's TRI developed under Section 313 of EPCRA and codified in 40 CFR 372.65 and also specifically excludes liquid or gaseous fluorocarbon or chlorofluorocarbon products, used chiefly as refrigerants (Illinois General Assembly 2022).” As shown, these definitions are much more specific. Incineration mostly stays the same but specifically excludes thermal oxidation as requested by Governor Pritzker in the veto of HB 3190. The definition of PFAS initially included in this bill was confusing to interpret. It included the original definition used in HB 3190- fluorinated organic chemicals containing at least one fully fluorinated carbon atom. Then, without an adjoining conjunction, the definition also included the list of PFAS on the Toxic Release Inventory list. However, another change in the definition of PFAS in HB 4818 included a specific exemption for refrigerants (Illinois General Assembly 2022).

In the original form of HB 4818, the incineration ban stayed similar to the final language used in HB 3190. It included that the incineration of any per- or polyfluoroalkyl substance, including but not limited to aqueous film-forming foam, was banned in the state of Illinois. A major difference included in HB 4818 was the introduction of unification language. In this ending clause of the bill, it was stated that if the US EPA proposed regulations for disposal of PFAS in the federal register, the federal policy would over rule the Illinois policy one year after implementation (Illinois General Assembly 2022).

HB 4818 was first amended in the House. The definition of incineration stayed the same, as it does throughout the life of the bill, but the definition of PFAS was changed slightly to include the word “and” between one fully fluorinated carbon atom and the list of PFAS included in the Toxic Release Inventory. In this amendment, the incineration ban stayed the same, as it does throughout the bill. The major change in this amendment excluded the unification language and added an exemption for landfills. In the final clause of the amended bill, “(i) the combustion of landfill gas from the decomposition of waste that may contain PFAS at a permitted sanitary landfill or (ii) the combustion of landfill gas in a landfill gas recovery facility that is located at a sanitary landfill (1)" was exempted from the policy (Illinois General Assembly 2022). HB 4818 stayed in this format passing through the house and sent to the Senate.

Unlike HB 3190, HB 4818 was revised twice in the Senate. In the first amendment, the definition of "perfluoroalkyl and polyfluoroalkyl substances" was changed to define "Toxic Release Inventory Perfluoroalkyl and Polyfluoroalkyl Substances or TRI-PFAS" (Illinois General Assembly 2022). The new definition for TRI PFAS excluded the "one fully fluorinated carbon atom" but kept the PFAS on the Toxic Release Inventory list and the exemption for refrigerants (Illinois General Assembly 2022). The rest of the bill stayed the same during this amendment. In the second Senate amendment, the definitions stayed the same, as well as the incineration ban. The main change in this amendment included further exemptions in the ending clause- "(iii) waste at a permitted hospital, medical, and infectious waste incinerator that meets the requirements of Subpart HHH of 40 CFR Part 62, Subpart Ec of 40 CFR Part 60, or the Board-adopted State Plan requirements for hospital, medical, and infectious waste incinerators, as applicable, or (iv) sludges, biosolids, or other solids or by-products generated at or by a municipal wastewater treatment plant or facility (Illinois General Assembly 2022)."

HB 4818 was sent back to the House for concurrence, in which the House concurred on both amendatory actions by the Senate (Illinois General Assembly 2022). Governor Pritzker approved HB 4818 and signed the legislation on June 8, 2022 with an immediate effective date. In Governor Pritzker's message concerning the signing of HB 4818, he signified the importance of Illinoisians health and safety but also stated a commitment to scientific research and following this correspondingly to the issue (WAND TV 2022). Although the unification language was removed early on in the formulation of HB 4818, this message from the Governor may indicate policy change in the future when scientific research on the disposal of PFAS is better developed.

The passing of this PFAS incineration ban policy may seem like a major victory to environmentalists and Democrats in the state of Illinois. However, there are many points to consider that are outlined in HB 4818. The definition of perfluoroalkyl and polyfluoroalkyl substances, or TRI-PFAS as written, severely cuts the number of chemicals regulated than what was first proposed in HB 3190. When this bill was passed in 2022, there were 176 PFAS listed on the Toxic Release Inventory with 4 more being added in 2023. Industry groups seem satisfied with this definition as this gives a manageable and concrete list of chemicals that are banned instead of guessing between a possible 9,000+ chemicals (Illinois General Assembly 2022).

The policy formulation in this step specifically, defining PFAS, caused tension between industry and environmental groups. The United Congregations of Metro East did not play a front role in formulating the policy, but they did make their concerns heard to other environmental groups who had an active role in this step. This included during a PFAS Town Hall held on January 11, 2022, hosted by the environmental group along with members of the Sierra Club, with a special participant, Senator Tammy Duckworth. The Sierra Club had proposed similar language used in HB 3190 to be included in HB 4818. The Illinois Environmental Council (IEC) expressed to the IMA that not containing "one fully fluorinated carbon atom" in the definition of PFAS was a non-starter for the group, meaning they would not settle for any less. However, the IMA expressed to the IEC that having that phrase in the definition would be a non-starter for the industry groups. Neither the industry group or environmental group wanted to let the Agency decide on the definition, so this part of the bill ended in industry's favor. Environmental groups in Illinois are hoping this legislation is just the beginning and eventually all PFAS will be banned for incineration in the state of Illinois.

This passed legislation included many other exemptions. The exemption of landfill gas is obviously favored by industry groups, but this point did not seem to get a lot of attention from environmental groups, which is surprising. Disposing of PFAS in landfills is not an ideal end-of-life technology. There is no destruction in this manner and rather PFAS will accumulate in the waste. Burning of this gas could potentially emit higher PFAS emissions, than if they were incinerated. Additionally, PFAS are not regulated as hazardous waste meaning they can enter a variety of landfill operations that do not have all the protections in place like a Subtitle C hazardous waste landfill would have. This creates the possibility of leaching of PFAS substances into the environment and even possibly into groundwater sources.

Another concerning exemption included in HB 4818 was the exemption of hospital, medical, and infectious waste incinerators. With the limited research conducted on PFAS destruction, a main point is the need for extremely high temperatures to break down the carbon-fluorine bond. Medical waste incinerators, as a group, have much lower temperature capabilities than hazardous waste incinerators, which shows that this operation could potentially emit higher concentrations of PFAS into the air than the banned operation. The last exemption stated that incineration of wastewater treatment plant sludges, biosolids, and by-products is not included in this policy. This wastewater treatment part seems to be almost a double standard. Wastewater treatment plants are not being held accountable for PFAS in their waste, so it seems that these facilities have been offered a pass to not be held to the same standards as other industries in Illinois. Treatment of PFAS at wastewater treatment plants is an emerging issue, so it would be reasonable to consider that this process may change in the near future.

Overall, HB 4818 seems to please some environmentalists and Democrats, as well as some industries due to exemptions and leniencies, but the policy has some major flaws. The policy seems premature in nature. Yes, it is true that further research needs to be developed to determine PFAS emissions and products of incomplete combustion in the incineration process. However, it is also false to completely ban incineration of these chemicals due to safety concerns. Research has not proven one way or another if incineration of PFAS is a desired end-of-life destruction technology or one that carries too many risks. Currently, hazardous waste incineration is the preferred technology for most halogen destruction, including chlorine, bromine, chlorofluorocarbons, and hydrofluorocarbons.

The exemptions allowed in this policy defeat many of the goals of the actors in this process. Governor Pritzker is focused on protecting health and safety of Illinoisians. However, higher risks are associated with some of these exemptions as discussed earlier. Cheryl Sommer from the United Congregations of the Metro East believes this ban will ignite safer disposal options for PFAS. Landfills and lesser incinerators do not provide any greater protection than hazardous waste incineration, despite the general public belief. A popular idea nationwide is to store per- and polyfluoroalkyl substances in place until a favored destruction technology is introduced. This also provides unnecessary risks while waiting for Federal and State Environmental Protection Agencies to complete research efforts.

Illinois HB 4818 may have been implemented prematurely or may have been proactive in reducing risk. The success of this legislation compared to the former can be attributed to the collaborative efforts during the policy formulation stage and greater efforts at policy legitimation from the environmental groups, conveying to the public the great dangers of burning per- and polyfluoroalkyl substances. It is unfortunate that this policy was based on assumptions and possibilities of risk rather than scientific evidence. Although the federal unification language was removed from HB 4818, there is good chance of policy change in the future if incineration does become the preferred destruction technology for PFAS. Moving into the macro-analysis section of this research, other state policy efforts at regulating PFAS are examined to determine if these were also politically motivated or based on scientific data. The incineration ban policy in Illinois is an interesting case study into how a specific legislation transpired; however, this is merely a historical description. With the lack of disposal policy for PFAS among states, the report is not generalizable to all states in the Union that have taken similar precautionary measures.

Macro-Analysis of State PFAS Water Policies

As mentioned in Chapters 1 and 2, states have created the foundation for PFAS policies within their state jurisdiction. Policies in states range from general restrictions on PFAS in consumer products and fire-fighting foams to more specific water advisories and particular disposal practices. In the macro-analysis section of this research, there will be a comprehensive evaluation of drinking water policies among states using multiple factors to determine a general conclusion on what drives PFAS policy formation and implementation. The macro-analysis is being performed because water policy is one of the most widespread PFAS policies that have been administered throughout the United States. In fact, to date it is the only Federal attempt to manage PFAS contamination and pollution. Although the focus of this study would have been solely on destruction and disposal policy pertaining to PFAS, there is not an available database that could fulfill the data analysis objectives of this research. Drinking water data has been made available for these emerging contaminants which allows the work to be completed in an external validity manner to apply to the fifty states and District of Columbia in the US as a whole instead of focusing simply on a few examples, as would have been the case for PFAS disposal.

Macro-Analysis Data Origin and Research Objectives

Data collected by the EPA in the Fifth Unregulated Contaminant Monitoring Rule (UCMR 5) released in July 2023 gives details on 29 individual PFAS and lithium collected from public water systems in the 50 states, tribal regions, and US territories (Office of Water 2023). The UCMR 5 data will be collected from 2023-2025, and this initial release of information represents only 7% of the total expected to be gathered from this effort. Monitoring data is being submitted by Public Water Systems (PWS) nationwide. As required by Section 201 of America's Water Infrastructure Act of 2018 amendments to the SDWA, these monitoring events must include small PWS serving less than 3,300 individuals, small PWS serving 3,300 to 10,000 individuals, and large PWS serving 10,001 individuals or greater (Office of Water 2021). All large systems and small systems serving 3,300 to 10,000 individuals are required to take part in UCMR 5 data collection, while only a nationally representative sample of small systems for less than 3,300 individuals is required to participate (Office of Water 2021). The initial data release from UCMR 5 is analyzed for the 29 PFAS monitored in the 50 states and District of Columbia to determine exceedance ratios. This explanatory variable is used in the macro-analysis to represent actual PFAS contamination within a state.

In addition to exceedance ratios from UCMR 5, other factors are analyzed to determine the presence of PFAS drinking water policy in an individual state. Military installations across the nation have been one of the main perpetrators for PFAS contamination in environmental media. The number of military installations in each state are considered to determine if this has any effect on the formation of PFAS water policy. Individual military installations in each state including US Army, US Navy, US Air Force, US Coast Guard, and US Marine branches were tabulated from an online source, www.military.com (Military Advantage 2023). This explanatory variable represents perceived PFAS contamination within a state.

Finally, each state's dominant political party will be included in this analysis to examine the influence politics has had in development of PFAS water policy. As determined throughout

US environmental policy history, the associated political party has been a main driving factor for federal and state legislation. To determine current state's dominant view, individual congressional districts within each state were listed with their US representative's associated party. This information was gathered from www.house.gov/representatives (House of Representatives 2023).

The research objectives for this macro-analysis are to understand the driving factors for PFAS environmental policymaking among state legislatures. It is vital to understand what compels these governmental bodies to promulgate standards for emerging environmental contaminants. In this way, researchers and advocates can focus their efforts on specific areas of scientific investigation in order to persuade other state and federal legislatures to regulate PFAS. Does actual or perceived PFAS contamination influence environmental policy? And if so, which has the greater effect? Or are environmental policymaking decisions among state governments purely politically motivated? It is predicted that actual contamination as recorded in the initial release of monitoring data under UCMR 5 or number of military installations will have a greater effect on the presence of a PFAS water policy within the state. The third explanatory variable, state's political party, is expected to not play a major role in whether a current policy exists.

The hypotheses examined in this study are as follows:

Hypothesis One (H1): States with higher exceedance ratios of 29 PFAS from the UCMR 5 have already developed PFAS water policies.

Hypothesis Two (H2): States with multiple and/or above the National average of military bases have already developed PFAS water policies.

Macro-Analysis Methodology

A Binomial Logistic Regression Generalized Linear Model (GLM) statistical test is used to analyze the effect of each independent factor listed in the section above on the result of each state either having or lacking a PFAS drinking water policy. If a state has an enforceable standard for any individual PFAS or has issued a health advisory for any individual PFAS in drinking water, it was included in this research as having a water policy. If an enforceable standard or health advisory is pending in state legislation or if guidance is absent completely, it was not included in the analysis. Additionally, some states that have policies pertaining to surface water and groundwater only were not included in the analysis since the UCMR 5 data is strictly for drinking water monitored at public water systems.

The UCMR 5 data exceedance ratios were determined by sorting through the initial release of occurrence data including the 29 PFAS constituents and lithium from this cycle. Before calculating, lithium monitoring data were removed because this metal is separate from the PFAS examined in this study and has alternative objectives not relative to this research. See Appendix B for details on state UCMR 5 data exceedance ratios. The data exceedance ratios were calculated by the total count of exceedances divided by the total count of monitoring points for PFAS.

As noted in the previous section, military bases throughout the nation were listed out to determine which were applicable to this research. Exclusion criteria to remove military installations from this research were units that exhibited one of the following characteristics- office buildings, command center operations only, medical centers, arsenals, and school research buildings that do not involve training. Additionally, joint bases, which are two separate military branches that have combined forces in an adjacent geographical location, are only counted as one installation within that state. Criteria for inclusion in this research are all active military installations, including all facilities which offer operational training or serve as a weapons' testing unit. The main thought for exclusion/inclusion criteria for this research is based on the potential for environmental contamination through the use of AFFF. Additionally, due to the wide variance among states and some states containing zero military installations, the weighted average number, 3.7, was used in the analysis creating groups of above or below the average. To avoid skewing the national average, states with zero military installations were removed from the calculation when determining the average number of military bases per state. Refer to Appendix C for details on military installations used in the analysis.

Only the 50 states and District of Columbia were included in this analysis, excluding US territories such as American Samoa and Puerto Rico. To determine the state's political association, the congressional districts within in each state were tabulated to ascertain the majority. In two states, there occurred an even split between democratic congressional districts and republican congressional districts. In this situation, the current governor of the state's political party was used as the dominant view. This situation presented itself with Minnesota and North Carolina, which both have democratic governors thus recording their dominant party as such for this research. Refer to Appendix A for details on state political party used in this analysis.

In this analysis, the response variable was state drinking water policy, set at a yes or no categorical value. This data had to be construed to operate correctly in the RStudio analysis; "no" values, or absent PFAS policy, were specified as "0" and "yes" values, or present PFAS policy, were specified as "1". State political party is a categorical explanatory variable and had to undergo modification to be ran in the model. Republican states were assigned a "1" value, and

Democratic states were assigned a “2” value. Appendix A contains the assigned political party information to each state based on congressional districts. UCMR 5 exceedance ratio data is a continuous numerical variable and was analyzed as such. Appendix B contains the exceedance ratio data for each state based on the initial release of occurrence data in 2023. Due to the wide variance in number of military bases, some with zero while California has the most installations at 22, the national average was computed and found to be 3.7. States with zero military bases were excluded when determining the national average. The states were then separated into groups either at, above, or below the average. These groups were set at “1” for below the national average or 0-2 military bases within the state, “2” for at the national average or 3-4 military bases within the state, or “3” for above the national average or 5+ military bases within the state. Appendix C contains information related to the names of military bases used for this analysis and total number per state, along with the assigned group number.

Macro-Analysis Results

State PFAS drinking water policies vary in statute, compliance, and enforceability among states. See Table 1 below for details on present water policies in each state, along with the constituents in which they regulate. As shown in the table, there is great variation among states as to which PFAS analytes are regulated and the type of standard or guidance issued. Although the differences are compelling, this is similar to other environmental policies that do not have a current federal floor. States make legislation decisions based on what best serves their citizens and unique situation.

Table 1: *State drinking water policies with affected PFAS and type of guidance*

State Drinking Water Policies		
State	**Standard/Guidance**	**PFAS Analytes**
Alaska	Health Advisory Level	PFOA, PFOS
California	Health Advisory Level	PFOA, PFOS, PFBS, PFHxS
Colorado	Health Advisory Level	PFOA, PFOS, PFNA, PFBS, PFHxS, PFOSA, 8:2 FTS, NEtFOSAA, NMeFOSAA
Connecticut	Health Advisory Level	PFOA, PFOS, PFNA, PFBA, PFBS, PFHxS, PFHxA, HFPO-DA, 6:2 chlorinated polyfluoroalkyl ether sulfonate (6:2 Cl-PFESA) (F-53B major and minor)
Delaware	Health Advisory Level	PFOA, PFOS, perfluorooctane sulfonic acid, potassium salt (PFOS-K), PFNA, PFBS, perfluorobutane sulfonic acid, potassium salt (PFBS-K), PFHxS, HFPO-DA
Hawaii	Health Advisory Level	PFOA, PFOS, PFNA, PFBA, PFBS, PFHxS, PFHxA, PFPeA, PFHpA, PFHpS, PFOSA, PFDA, perfluorodecane sulfonic acid (PFDS), PFUnA, PFDoDA, PFTrDA, PFTA, HFPO-DA
Illinois	Health Advisory Level	PFOA, PFOS, PFNA, PFBS, PFHxS, PFHxA
Maine	Enforceable MCL	PFOA, PFOS, PFNA, PFBS, PFHxS, PFHpA, PFDA
Maryland	Health Advisory Level	PFHxS
Massachusetts	Enforceable MCL	PFOA, PFOS, PFNA, PFHxS, PFHpA, PFDA
Michigan	Enforceable MCL	PFOA, PFOS, PFNA, PFBS, PFHxS, PFHxA, HFPO-DA
Minnesota	Health Advisory Level	PFOA, PFOS, PFBA, PFBS, PFHxS, PFHxA
Nevada	Health Advisory Level	PFOA, PFOS, PFBS
New Hampshire	Enforceable MCL	PFOA, PFOS, PFNA, PFHxS
New Jersey	Enforceable MCL	PFOA, PFOS, PFNA
New Mexico	Health Advisory Level	PFOA, PFOS, PFHxS
New York	Enforceable MCL	PFOA, PFOS
North Carolina	Health Advisory Level	HFPO-DA
Ohio	Health Advisory Level	PFOA, PFOS, PFNA, PFBS, PFHxS, HFPO-DA
Oregon	Health Advisory Level	PFOA, PFOS, PFNA, PFHxS, PFHpA, PFOSA
Pennsylvania	Enforceable MCL	PFOA, PFOS
Rhode Island	Enforceable MCL	PFOA, PFOS, PFNA, PFHxS, PFHpA, PFDA
Vermont	Enforceable MCL	PFOA, PFOS, PFNA, PFHxS, PFHpA
Washington	Health Advisory Level	PFOA, PFOS, PFNA, PFBS, PFHxS, HFPO-DA
Wisconsin	Enforceable MCL	PFOA, PFOS

PFAS drinking water policy among states is summarized in Figure 6 below. Additionally, this figure depicts the results from all explanatory variables used in the analysis. In this figure, note that PFAS drinking water policy and state political party have a binomial response, absent/present and republican/democratic, respectively. Military bases in this figure have a trinomial response, separated by groups 1/2/3, based on the national average. The UCMR 5 exceedance ratio map is a continuous response variable, meaning the colors on this map represent values lowest to highest by deepening color scheme.

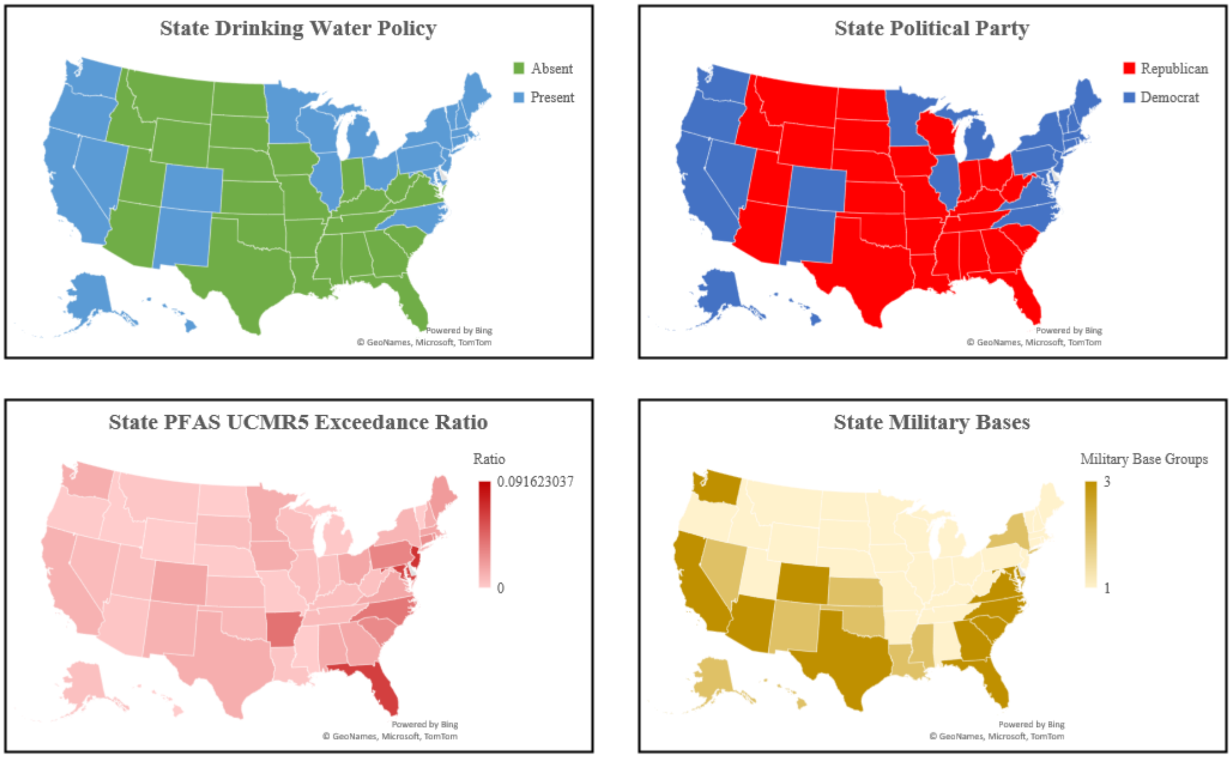


Figure 6: Maps depicting analytical variables

See Figure 7 below for relationship plots representing these factors against state drinking water policy. Observing the effect plot (a) from Figure 7, it is shown that there is a positive relationship between a present PFAS drinking water policy within a state that is Democratic. Figure 7 effect plot (b) shows a positive relationship between a present PFAS drinking water policy within states that have higher exceedance ratios as reported under the initial release of UCMR 5. However, effect plot (c) from Figure 7 shows almost no effect between the number of military bases within a state based on the national average and the presence or absence of a PFAS drinking water policy. A positive relationship between these variables was expected, but the result appears null, with a slight negative relationship.

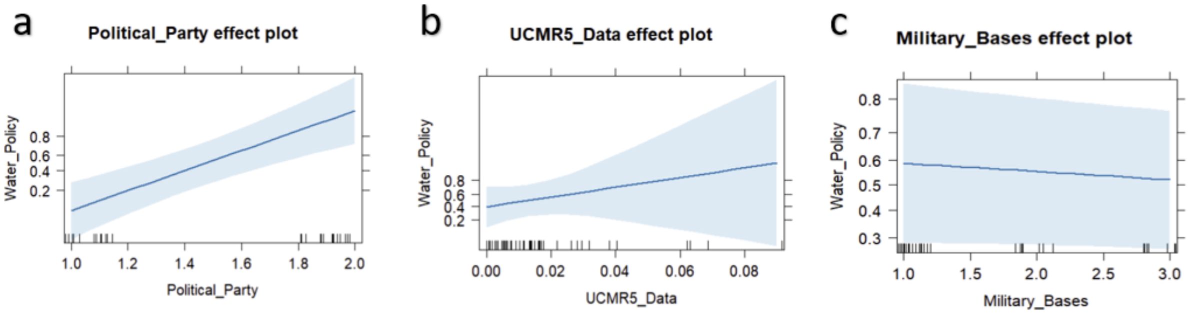


Figure 7: Effect plots for Water Policy explanatory variables relationships. Water policy is represented in the data model as a “0” for a state not having a PFAS drinking water policy and “1” for a state having a PFAS drinking water policy. Graph (a) depicts political party effect on state water policy, where “1” represents Republican affiliation and “2” represents Democratic affiliation. Graph (b) depicts UCMR 5 data exceedance ratio effect on state water policy. Graph (c) depicts military base national average effect on state water policy, where “1” represents below the national average, states having 0-2 military bases; “2” represents at the national average, states having 3-4 military bases; “3” represents above the national average, states having 5+ military bases.

Utilizing RStudio to analyze the data using a binomial logistic regression GLM, only one factor shows a significant effect on the outcome of a state already harboring a PFAS drinking water policy. A binomial GLM was chosen for this research because it does not require normal distribution or normal errors for the data. This is an ideal model for the data used in this research due to the binary nature of multiple variables. Political party is the only factor notably influencing states’ PFAS water policy development. Hypothesis One (H1) is not supported by the data model. Concurrently, Hypothesis Two (H2) is also not supported by the data model. See Table 2 below for a summary of results from the analysis.

Table 2: *Binomial logistic regression generalized linear model results.*

Predictor Variable	Std. Error	Z-Value	P-Value
Political Party	1.151	4.453	8.47E-06*
UCMR 5 Exceedance Ratio	37.411	0.910	0.363
Number of Military Bases	0.101	-1.314	0.189

* Indicates significant p-value (α ≥ 0.05).

Federal PFAS NPDWR Proposed Rule

Although the main focus of this research and the macro-analysis conducted is centered around states' PFAS policies, it is important to also examine what is being done at the federal level. States' policy efforts were chosen as the main point of this research because there are concrete regulations currently in place. Whilst falling behind the states' timeline for promulgating legislation pertaining to PFAS, the federal EPA is making strides toward beginning regulation of these constituents. As noted with the states analysis, drinking water is the regulatory inception for PFAS at the federal level as well. This section summarizes the emergence of PFAS policy from the federal government by describing the proposed rulemaking for regulating PFAS in drinking water nationwide. The following section provides an analysis of the PFAS policy goals set by the federal government.

In the spring of 2023, the United States EPA proposed the first drinking water standards for six PFAS under the NPDWR. Except for permit requirements for specific facilities, NPDWR under the SDWA is the first attempt by the federal government to regulate PFAS discharges. The new statute will require facilities to update monitoring and treatment technologies to oversee PFAS releases into drinking water which includes action items if potable water is above the standards. This proposed rule is qualitatively analyzed by examining publicly available documents released by the EPA to attempt to explain why this was the first federal policy introduced that regulates PFAS. Furthermore, an in-depth examination to the details surrounding this policy, including standard levels and feasibility concerns, is provided.

On March 14, 2023, the US EPA made a huge advancement in the PFAS regulatory framework by proposing drinking water standards for specific compounds. The NPDWR developed under the SDWA allowed the EPA to set proposed standards for PFOA, PFOS, PFNA, HFPO-DA (GenX chemicals), PFHxS, and PFBS (2023j). The proposed rule was submitted to the Federal Register on March 29, 2023, and the public comment period ended on May 30, 2023. However, the NPDWR for PFAS is not final and does not require action until the EPA reviews the input from the public, if it deems necessary, and finalizes the rule (EPA 2023j). The enforceable levels set in the proposed rule are referred to as MCLs. Also included in the rule are health-based goals that are not enforceable referred to as Maximum Contaminant Level Goals (MCLG).

The MCLG for PFOA and PFOS is set to zero, a desirable goal but not realistic of achievement in most areas. As mentioned, PFAS contamination is widespread and continues to enter the environment through industrial processes. If production and use continue, the goal of zero for PFOA and PFOS will continue to be unattainable. The MCL for PFOA and PFOS is set to an enforceable limit of 4.0 parts per trillion (ppt). The MCLG and MCL are the same for the combination of the other four PFAS- PFNA, HFPO-DA, PFBS, and PFHxS, set to a hazard index level of 1.0 (EPA 2023j). This hazard index, like the one used for the CERCLA, is a mathematical tool used in regulatory standards to evaluate health risks of contaminants. The specific hazard index level of 1.0 for PFNA, HFPO-DA, PFBS, and PFHxS, consists of a combination of ratios of these PFAS in a water sample. The measured concentration of each will be divided by their set health-based value, and the total of all these concentrations will need to be less than 1.0 (unitless) to be in regulatory compliance. The health-based water concentrations (HBWC) have been set as 10 ppt for HFPO-DA, 2000 ppt for PFBS, 10 ppt for PFNA, and 9.0 ppt for PFHxS (EPA 2023j).

These new standards under the National Primary Drinking Water Regulations apply to public water systems which are defined in the Federal Register as “a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals. Such term includes (i) any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system, and (ii) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system (Cornell Law School)." Currently, 148,000 public water systems supply ninety percent of Americans drinking water in their homes as regulated under the NPDWRs (EPA 2023l). New standards developed under this provision are a huge undertaking for the owners and operators of these public water systems.

The EPA is required to apply feasibility for its actions in congruence with newly proposed drinking water standards for contaminants. The feasibility of the proposed MCLs is attributed to availability of analytical EPA approved methods capable of measuring these PFAS compounds at or below their proposed limit. Also, availability of treatment technology to treat PFAS contaminated water to at or below their proposed limits is taken into account for feasibility purposes (EPA 2023j). Additionally, a cost-benefit analysis was performed for the NPDWR. The benefits are weighed as the prevention of PFAS-related illnesses and deaths, while the costs are weighed as expenses incurred by the public water systems for monitoring, treatment technologies, record-keeping, and reporting. Costs to agencies just involve the implementation of the rule, and the current EPA Administrator, Michael Regan, has confirmed that the benefits of this rule outweigh the costs (EPA 2023j). Although the process of developing these standards for PFAS in drinking water was extensive, contentions are still sure to arise in the implementation of the rule.

Inclusion of stakeholders in the rule-making process is a crucial action for agency rule promulgation. Public meetings involving these associated contributors, along with state, local, and tribal governmental bodies, took place before the proposed rule was filed in the Federal Register (EPA 2023j). The Science Advisory Board and National Drinking Water Advisory Council also played a vital role in developing the rule. In addition to this, as noted earlier, the public comment period for the PFAS NPDWRs ended on May 30, 2023. During this 60-day period, interested parties had an additional opportunity to provide feedback on the rule, if they were not previously included in meetings, which could encompass challenges that may be had during the implementation.

Throughout this process, the NPDWR should satisfy most interested parties; however, there will still exist some opposition to the rule. A main contention will be the new burden of responsibilities and costs suffered by public water systems. These companies would become accountable for monitoring these six PFAS levels in water, notifying the public of these levels, and reducing contaminant levels if they exceed the standard (EPA 2023j). The requirements for the vast number of public water systems in the United States may pose severe hurdles to update monitoring equipment and technology capable of lowering the PFAS contaminants to their proposed standards. Legal actions may be taken against the EPA which challenge costs associated with the rule and feasibility of implementation, especially for small and rural water companies. In addition to costs, the burden of reporting PFAS concentrations to the public, as prescribed by the SDWA, may cause an overload of citizen suits against these companies trying to meet the standards. The Environmental Protection Agency is taking a bold and necessary step forward in regulating these emerging contaminants through the SDWA regulations. There will be some resistance to the rule by affected parties and possibly citizens of the general public, but protecting public health through drinking water safety is likely to be upheld in court. Analysis of this rule-making process deems the agency’s actions necessary and lawful.

The proposed rulemaking for NPDWRs under the SDWA for the six PFAS will be the propelling factor for regulating PFAS in other areas of environmental contamination. Specifically, the drinking water regulations are most likely the first to materialize due to the simple nature of detecting levels of PFAS in water. Using EPA approved methods, Methods 533 and 537.1 both involving a solid phase extraction and liquid chromatography with tandem mass spectrometry, PFAS are able to readily be identified in liquid samples using familiar technologies employed by most public water systems (EPA 2023j). Moreover, drinking water contamination is a direct and tangible threat to public health, making this regulation heavily supported by the general public and thereby, important influence to move forward with the rules despite some contentions. The promulgation of this rule will build a foundation for similar PFAS regulations in pollution protection.

The above example is just one expanse where the federal government is attempting to regulate PFAS. This will be a driving factor for other areas of PFAS policy at the federal level once it is officially promulgated. The NPDWR for the six PFAS is one of many initiatives commenced by the federal EPA. In the next section, the EPA’s PFAS Strategic Roadmap is introduced and analyzed to determine if progress is being made in other areas for PFAS regulation. It is important to recognize PFAS strategies as a whole since this has become a wicked environmental issue. Regulating one domain is an honest start, but unfortunately, this will not make much of a difference in the widespread contamination of PFAS if other areas are not similarly addressed.

US EPA's PFAS Strategic Roadmap Analysis Research Objectives

The US EPA released the PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024 on October 18, 2021, which outlined specific goals for the agency to meet in developing regulatory action for handling PFAS. Most goals outlined in the plan were given distinct deadlines, while other goals were deemed as ongoing efforts. The plan was set for efforts during the 2021-2024 years because this coincides with the first term of the Biden-Harris presidential administration (EPA 2021b). A similar project was released by the EPA in 2019 called the PFAS Action Plan. While this plan had a similar strategy with goals to be met by specified deadlines, the document was more explanatory and informative along with fewer objectives. The release of the PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024 provided updated actions originating from further research that has been completed in regard to these chemicals.

In this plan, the EPA puts emphasis on this being an agency-wide initiative while also focusing on the complete lifecycle of PFAS starting from their manufacture, throughout commerce, use, and ultimate disposal. The PFAS Strategic Roadmap has three main overarching objectives- research, restrict, and remediate. All specific goals outlined in the plan falls under one of these three categories. Research is an essential goal for PFAS strategy moving forward since there are still so many unknowns associated with these chemicals. These efforts include work on public health and toxicity assessments, effects on the environment, and developing scientific knowledge further to make informed decisions on best available technologies (EPA 2021a). Restrict and remediate are both important targets for this plan since nation-wide contamination already exists but also since PFAS are still being used and produced in industry which will continue pollution in the environment if not properly managed. Restrict objectives in this plan are focused on finding a way to properly govern the routes and amounts in which the agency will allow PFAS to enter air, water, and land media through their current use in industry

(EPA 2021b). Remediate efforts will focus on the current contamination in water and land and accelerate the work of getting these areas and media cleaned up in order to protect public health and the environment (EPA 2021b).

The research objectives for this federal PFAS Strategic Roadmap analysis are less thorough than the macro-analysis provided in this research at the state level. However, it would come across as negligent to ignore the efforts at the federal level. In this manner, this research provides a comprehensive look at PFAS policy across United States federalism as a whole. In analyzing the completion rates for the federal EPA's PFAS Strategic Roadmap objectives, it is expected that all goals have been met by their specified deadlines.

US EPA's PFAS Strategic Roadmap Analysis Methodology

Using the PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024, each objective is analyzed to determine if the deadline has been met. This gives an introspective as to whether the federal agency is keeping on track with their initiatives to regulate PFAS. Correspondingly, a discussion follows as to why some goals were completed versus the ones that are overdue. Laying out a comprehensive plan shows promise that the EPA is committed to tackling the PFAS issue; however, if goals are simply placeholders and not being attained, this causes the initiative to be less significant of an action on the federal agency's behalf.

The goals provided in the PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024 were divided among the agency's corresponding offices- Office of Chemical Safety and Pollution Prevention, Office of Water, Office of Land and Emergency Management, Office of Air and Radiation, Office of Research and Development, and Cross-Program, meaning agency-wide approaches (EPA 2021a). Throughout the publication, some goals were assigned "Efforts Ongoing", instead of a specific season and year. For these actions, the results were counted as nil and not included in the overall completion rate for the office. If an action was completed, it is counted as 100% in the analysis. If an action was overdue for completion, it is counted as 0% in the analysis. If an action was partially completed, it is counted as 50% in the analysis. Although most goals were given deadlines between 2021-2023, some were assigned 2024 target dates and thus have completion pending. These results were also counted as nil and not included in the overall completion rate for the office.

US EPA's PFAS Strategic Roadmap Analysis Results

The Office of Chemical Safety and Pollution Prevention was assigned six actions on the roadmap, four of which had deadlines. Three of the four goals given to the Office of Chemical Safety and Pollution Prevention were completed, while one was only partially done by the deadline. This results in the office accomplishing an 87.5% completion rate. The Office of Water was assigned the most goals in the EPA's Strategic Roadmap totaling twelve actions, all of which were given deadlines. Two of these goals had separate deadlines for proposed and final rules which were split up upon determining the completion rate. In this case, eleven of the fourteen goals were evaluated since the other three had 2024 deadlines. The Office of Water has accomplished a 54.5% completion rate for the goals it was assigned. The Office of Land and Emergency Management had three total goals, one which had to be split into two since proposed and final rules were assigned two different deadlines. This results in the office accomplishing a 50% completion rate. The Office of Air and Radiation was only given one goal, which has been partially completed, resulting in this office obtaining a completion rate of 50%. The Office of Research and Development was assigned three initiatives, all of which are determined to have "Efforts Ongoing", which results in a nil completion rate for this office. Finally, the Cross-Program actions were assigned six goals. One of these was not set a deadline, and analyzing the final five resulted in the Cross-Program actions only having a completion rate of 40%. Chapter 4 provides further detail on goal completion rate, while also providing insight into each objective and the progress or lack thereof that has been made.

Table 3: *EPA's PFAS Strategic Roadmap and Progress*

Office of Chemical Safety and Pollution Prevention	
Objective	**Deadline**
Publish national PFAS testing strategy	Fall 2021*
Ensure a robust review process for new PFAS	Efforts ongoing*****
Review previous decisions on PFAS	Efforts ongoing*****
Close the door on abandoned PFAS and uses	Summer 2022*
Enhance PFAS reporting under the Toxics Release Inventory	Spring 2022*
Finalize news PFAS reporting under TSCA section 8	Winter 2022**
Office of Water	
Objective	**Deadline**
Undertake nationwide monitoring for PFAS in drinking water	Fall 2021*
Establish a national primary drinking water regulation for PFOA and PFOS	Proposed- Fall 2022*
Establish a national primary drinking water regulation for PFOA and PFOS	Final- Fall 2023***
Publish the final toxicity assessment for GenX and five additional PFAS	Fall 2021, ongoing**
Publish health advisories for GenX and PFBS	Spring 2022*
Restrict PFAS discharges from industrial sources through a multi-faceted Effluent Limitations Guidelines program	2022, ongoing*
Leverage NPDES permitting to reduce PFAS discharges to waterways	Winter 2022*
Publish multi-laboratory validated analytical methods for 40 PFAS	Fall 2022***
Publish updates to PFAS analytical methods to monitor drinking water	Fall 2024****
Publish final recommended ambient water quality criteria for PFAS	Proposed- Winter 2022***
Publish final recommended ambient water quality criteria for PFAS	Final- Fall 2024****
Monitor fish tissue for PFAS from the nation's lakes and evaluate human biomarkers for PFAS	Summer 2022**
Finalize list of PFAS for use in fish advisory programs	Spring 2023***
Finalize risk assessment for PFOA and PFOS in biosolids	Winter 2024**
Office of Land and Emergency Management	
Objective	**Deadline**
Propose to designate certain PFAS as CERCLA hazardous substances	Proposed Spring 2022*
Propose to designate certain PFAS as CERCLA hazardous substances	Final Summer 2023***
Issue advance notice of proposed rulemaking on various PFAS under CERCLA	Spring 2022*
Issue updated guidance on destroying and disposing of certain PFAS and PFAS-containing materials	Fall 2023***
Office of Air and Radiation	
Objective	**Deadline**
Build the technical foundation to address PFAS air emissions	Fall 2022, ongoing**

Office of Research and Development	
Objective	**Deadline**
Develop and validate methods to detect and measure PFAS in the environment	Ongoing actions*****
Advance the science to assess human health and environmental risks from PFAS	Ongoing actions*****
Evaluate and develop technologies for reducing PFAS in the environment	Ongoing actions*****
Cross- Program	
Objective	**Deadline**
Engage directly with affected communities in every EPA Region	Fall 2021, ongoing*
Use enforcement tools to better identify and address PFAS releases at facilities	Ongoing actions*****
Accelerate public health protections by identifying PFAS categories	Winter 2021, ongoing***
Establish a PFAS voluntary stewardship program	Spring 2022***
Educate the public about the risks of PFAS	Fall 2021, ongoing*
Issue an annual public report on progress towards PFAS commitments	Winter 2022, ongoing*

Objective Completion Legend:
*: Objective completed by deadline.
**: Objective partially completed by deadline.
***: Objective overdue.
****: Objective pending completion for future deadline.
*****: Efforts ongoing. Objective not included in overall completion rate.

CHAPTER IV

DISCUSSION AND CONCLUSION

Significance of PFAS Policy Examination

Policy surrounding PFAS is an emerging topic with the awareness growing around the extent of contamination and detrimental effects to human health in the United States. Developing standards and regulations that protect public health and the environment needs to be an urgent matter, while still considering the best available scientific information. While the federal government is taking time to develop PFAS policies, states are taking quicker action. This preempts that protection of human health from these harmful contaminants are falling on the state responsibility. There are several factors that can lead to developed PFAS legislation. While many varying public policies exist among states pertaining to PFAS, as discussed throughout Chapter 2, it is crucial to understand the motivation behind these in order to replicate or diverge from hasty decisions. This research is a beginning attempt to explain the effect some of these variables have on policy development.

UCMR 3 vs. UCMR 5 Data Discussion

As explained in Chapter 2, the UCMR 3 cycle was the first nationwide monitoring event to contain PFAS in the data. This series included the six PFAS compounds- PFOS with a minimum reporting level of 0.04 µg/L, PFOA with a minimum reporting level (MRL) of 0.02 µg/L, PFNA with an MRL of 0.02 µg/L, PFHxS with an MRL of 0.03 µg/L, PFHpA with an MRL of 0.01 µg/L, and PFBS with an MRL of 0.09 µg/L (EPA 2022c). These analytes were monitored and reported using Method 537.1 (EPA 2022c). This EPA approved method was developed to support UCMR 3 monitoring and has since been updated. At the time of the UCMR 3 data collection, there were zero PFAS drinking water standards among states. This was the very beginning attempt at organizing a nationwide dataset to compile the extent of PFAS contamination information.

Recall in Chapters 2 and 3 the information stated pertaining to the UCMR 5 cycle. This is the second cycle of UCMR that PFAS constituents have been included in and to a much greater extent than the previous. UCMR 5 contains 29 specific chemicals for collection; see Table 4 for individual PFAS examined during this phase with their corresponding MRLs. These analytes were monitored and reported using EPA Method 537.1 and EPA Method 533 (Office of Water 2023). Recall in Chapter 2 the discussion regarding PFAS analytical detection methods. Method 537.1 received an update to its procedure after the UCMR 3 cycle, before the UCMR 5 cycle. There is some overlap between constituents analyzed on both methods, but overall, between the two lists, there are only 29 PFAS that can be analyzed in drinking water using the two methods combined, thus further explaining why these were chosen for the UCMR 5 cycle.

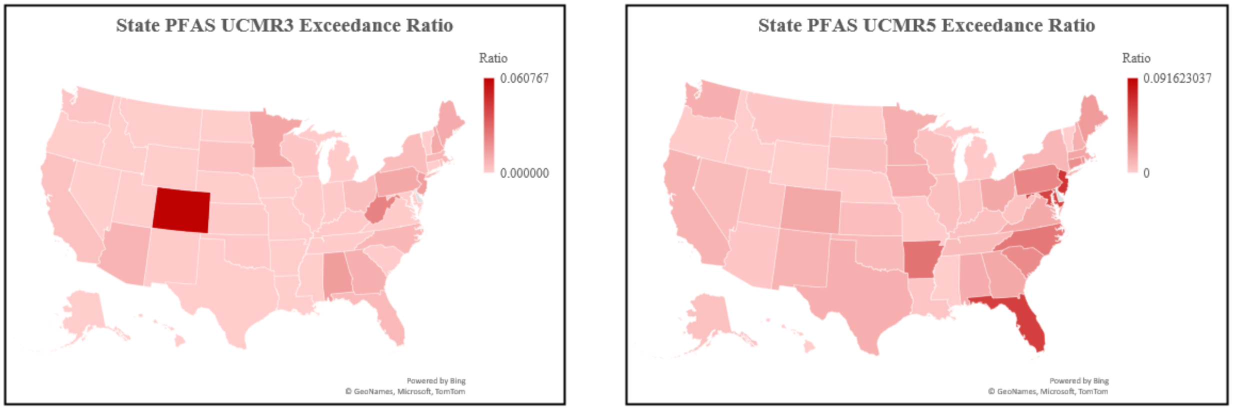
Table 4: *PFAS included in the UCMR 5 monitoring collection*

Contaminant	**MRLs (µg/L or ppb)**
11-chloroeicosaflyoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	0.005
1H, 1H, 2H, 2H-perfluorodecane sulfonic acid (8:2 FTS)	0.005
1H, 1H, 2H, 2H-perfluorohexane sulfonic acid (4:2 FTS)	0.003
1H, 1H, 2H, 2H-perfluorooctane sulfonic acid (6:2 FTS)	0.005
4,8-dioxa-3H-perfluorononanoic acid (ADONA)	0.003
9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	0.002
hexafluoropropylene oxide dimer acid (HFPO-DA)(GenX)	0.005
nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	0.020
perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	0.003
perfluoro-3-methoxypropanoic acid (PFMPA)	0.004
perfluoro-4-methoxybutanoic acid (PFMBA)	0.003
perfluorobutanesulfonic acid (PFBS)	0.003
perfluorobutanoic acid (PFBA)	0.005
perfluorodecanoic acid (PFDA)	0.003
perfluorododecanoic acid (PFDoDA)	0.003
perfluoroheptanesulfonic acid (PFHpS)	0.003
perfluoroheptanoic acid (PFHpA)	0.003
perfluorohexanesulfonic acid (PFHxS)	0.003
perfluorohexanoic acid (PFHxA)	0.003
perfluorononanoic acid (PFNA)	0.004
perfluorooctanesulfonic acid (PFOS)	0.004
perfluorooctanoic acid (PFOA)	0.004
perfluoropentanesulfonic acid (PFPeS)	0.004
perfluoropentanoic acid (PFPeA)	0.003
perfluoroundecanoic acid (PFUnA)	0.002
N-ethyl perfluorooctanesulfonamidoacetic acid (NEtFOSAA)	0.005
N-methyl perfluorooctanesulfonamidoacetic acid (NMeFOSAA)	0.006
perfluorotetradecanoic acid (PFTA)	0.008
perfluorotridecanoic acid (PFTrDA)	0.007

Table 4 information gathered from online EPA Fact Sheet (Office of Water 2021).

When comparing the occurrence data between the UCMR 3 and UCMR 5 cycles, it is shown that most states saw an overall increase in PFAS contamination in drinking water. Arizona, Colorado, and West Virginia were the only three states to experience a decrease in exceedance ratios. Additionally, some states exhibited zero data exceedance ratios in both the UCMR 3 and UCMR 5 cycles making these percent changes null. These states include District of

Columbia, Hawaii, Idaho, Mississippi, North Dakota, Vermont, and Wyoming. Figure 8 below depicts maps for these data exceedance ratios between UCMR 3 and UCMR 5. See Appendix D for comparisons of data exceedance ratios between the two monitoring cycles and relevant percent changes for each state.



State PFAS UCMR3 Exceedance Ratio

State PFAS UCMR5 Exceedance Ratio

Figure 8: Map comparison of UCMR 3 and UCMR 5 data exceedance ratios

As previously stated, UCMR 3 ran for the years 2013-2015, and UCMR 5 is currently in progress for years 2023-2025. There were many events pertaining to PFAS that occurred in this 10-year period. First and foremost, the topic of this research, the development of drinking water policies among many states took place. Additionally, the US manufacturing ban of PFOA and PFOS happened during this time span. This may seem to disagree with the data since the majority of states did experience an increase in overall PFAS data exceedance ratios between the two cycles. However, during this time, much research and analytical development took place surrounding the topic of PFAS contamination. As mentioned, an additional analytical method was employed for monitoring and detecting PFAS. Although PFOA and PFOS were banned from production in the United States, manufacturers are still able to import these chemicals from other countries. There has also been a shift between the legacy PFAS and shorter chain PFAS in appearing in contaminated environmental media. Furthermore, as technological development increases, these constituents are now able to be detected at smaller concentrations in drinking water samples. The six PFAS included in UCMR 3 and all those added to UCMR 5, are now detectable one-thousandth of a microgram per liter in comparison to the earlier hundredth of a microgram per liter. Although there have been regulatory updates, the overall increase in data exceedance ratios can be scientifically explained.

Macro-Analysis of State PFAS Water Policies Discussion

As outlined in Chapter 3, three explanatory variables were analyzed to determine the effect on whether a state already has a developed drinking water policy. The Binomial Logistic GLM provided that political party was the only significant factor influencing the presence or absence of a state drinking water policy. The exceedance ratio from the first data release of UCMR 5 and number of military bases did not have a significant effect. The p-value was set to $\alpha=0.05$, indicating that there is 95% confidence that the results are statistically significant and not a random effect. In this case, we accept the null hypothesis that UCMR 5 data exceedance ratio does not have an effect on states' development of PFAS drinking water policy. Agreeably, we accept the null hypothesis that number of military bases does not have an effect on states' development of PFAS drinking water policy. However, we fail to reject the null hypothesis that political party does not have a significant effect on states' development of PFAS drinking water policy. Recall in Chapter 3 that both hypotheses for this research were disproven by the statistical results.

The effect plots in Chapter 3, Figure 7 depict the relationships between the explanatory variables and outcome variable of water policy. Although this research did not plan or predict a hypothesis regarding political party having a major effect on a state water policy, this was the only significant factor influencing the outcome variable with a p-value of 8.47E-06. The standard error for the political party variable was 1.151 meaning this data fit the regression line rather well with little deviance. Taking these two factors into consideration, we can be fairly certain that the political party does influence a state's water policy based on the statistical analysis conducted. This outcome does not explain an exceptional circumstance as unfortunately environmental policy history is riddled with similar examples. Within the United States governmental structure, environmental initiatives seem to be a more upfront approach for Democratic officeholders while these tend to be laxed or reversed when a Republican officeholder takes position.

The UCMR 5 data exceedance ratio variable did not have a significant effect on the outcome of a present state water policy as predicted in Hypothesis 1 (H1), with a designated p-value of 0.363. As noted in Chapter 3 Table 2, this variable shows a larger standard error value of 37.411. With this occurrence, the multicollinearity was checked to ensure the p-values and associated results were accurate. Variation Inflation Factors (VIF) can be used to determine severity of multicollinearity. See Table 5 below for a summary of multicollinearity results for each variable. Since all VIFs were close to 1, this indicated that multicollinearity only had a mild effect and does not require data restructuring to trust the outputs of the statistical model. After further examination, the large standard error value is likely related to the wide variance of UCMR 5 data exceedance ratios, ranging from 0.000000 to 0.091623, and the relatively small sample size. This variable is a measure of actual contamination within states and shows that this is not the main motivation for states to develop PFAS drinking water policies.

Table 5: *Multicollinearity results*

Predictor Variable	**Std. Error**	**Variation Inflation Factor (VIF)**
Political Party	1.151	1.139
UCMR 5 Exceedance Ratio	37.411	1.061
Military Bases	0.101	1.175

Note all VIF's are close to one indicating there was only a mild effect of multicollinearity on the explanatory variables.

Number of military bases in a state established from the national average also did not show a significant effect on a state's water policy. Hypothesis 2 (H2) was therefore also rejected by the analysis since this variable displayed a p-value of 0.189. The standard error for military bases is 0.101 which can be interpreted as little deviance since the data is well fit to the regression line. Similar to the rejection of Hypothesis 1 (H1), the number of military bases reflects potential contamination within a state, and this is not a driving factor for policy creation within state legislatures.

US EPA's PFAS Strategic Roadmap Progress Discussion

Although states are directing and setting the foundation for PFAS policy, it is important to also examine the federal government's role in protecting human health and the environment from PFAS contamination. The PFAS Strategic Roadmap: EPA's Commitment to Action 2021-2024 provides the most comprehensive plan to date for the federal government to intervene in the PFAS issue. As discussed in Chapter 3, this roadmap assigned specific goals and deadlines across the agency to address the matter. Recall the detailed table in Chapter 3, Table 3. These goals were divided between EPA departments in order to be addressed by the appropriate branch of the agency.

As noted in the Cross-Program objectives, the EPA is responsible for issuing an annual public report showing the progress towards the PFAS initiatives set out in the PFAS Strategic Roadmap. The first of these progress reports was released in November 2022 and named "EPA's

Strategic Roadmap: A Year of Progress”. As of November 2023, there has not been a second-year report on the progress of these objectives. In the Year of Progress release, the EPA outlined the initiatives accomplished at the time. The Office of Chemical Safety and Pollution Prevention was the most successful at completing its assigned objectives, with a completion rate of 87.5%. The National PFAS Testing Strategy was released in October of 2021 and is a vital step towards organizing classes of PFAS (EPA 2022b). Additionally, this office removed 12 PFAS approved for use as inert ingredients in pesticides (EPA 2022b). Finally, there have been updates made to reporting requirements for PFAS listed on the TRI, removing the *de minimis* for these chemicals (EPA 2023k). The *de minimis* exclusion allowed chemical companies to avoid reporting of PFAS if they were under a certain concentration.

The Office of Water was assigned the most objectives under the PFAS Strategic Roadmap and have achieved a 54.55% completion rate. The nationwide monitoring of PFAS in drinking water initiative has been completed with the onset of UCMR 5. Recall in Chapter 3 the NPDWR set for six PFAS compounds. This was an initiative under the roadmap that has met the initial deadline of proposing the rule. However, the final rule has been pushed back for release, making the second half of this objective overdue for completion. In June 2022, this office completed updated health advisories for PFOA and PFOS in drinking water and released final health advisories for HFPO-DA (GenX) and PFBS in drinking water (EPA 2022b). In addition to health advisories, the EPA Office of Water also published a final toxicity assessment for PFBS in April 2021 and for HFPO-DA (GenX) in October 2021 (EPA 2022b). As mentioned in Chapter 1, PFNA and PFHxS are in the process of having toxicity assessments completed. The Office of Water released its Effluent Limitations Guidelines Plan 15 in January 2023 which will eliminate some of the upstream discharges from polluters into the nation’s waterways (EPA 2023k). In this plan, it was determined that a rulemaking for landfill leachates in regards to PFAS is warranted and will make revisions to pretreatment standards and effluent guidelines for this category (EPA 2023k). Concurrently with the Effluent Limitations Guidelines Plan 15, EPA also plans to address PFAS discharges through the source by including standards on facility's NPDES permits under the Clean Water Act. A memo was released by the EPA office in April 2022 which will ultimately reduce PFAS entering waterways and begin more comprehensive monitoring at the affected facilities (EPA 2023k).

The Office of Land and Emergency Management was only given four objectives in the PFAS Strategic Roadmap and has completed half of them. As discussed extensively in Chapter 2, there has been a proposed rulemaking to designate PFOA and PFOS as hazardous substances under CERCLA. This rulemaking was published to the Federal Register in September 2022, but we have yet to see a final rule codified (EPA 2023c). This part of the objective is overdue as it was set to be released in Summer 2023 but the agency has set a secondary publish date for February 2024 (Office of Information and Regulatory Affairs 2023). Also mentioned in Chapter 2 was the ANPRM for listing several additional PFAS as hazardous substances under CERCLA which was completed by the office in April 2023 (Federal Register 2023). The Office of Air and Radiation was only given one objective to complete on the PFAS Strategic Roadmap which has only been partially completed by its' deadline. Although only a singular initiative was specified, this office has been entrusted with an immense task to lay the foundation for PFAS in air emissions. In this objective, the Office of Air and Radiation plans to address PFAS air emission sources, develop monitoring techniques for stack emissions and ambient air, advance research on clean-up technologies, and examine fate and transport mechanisms further for PFAS in air (Reeder and Anderson 2023). The office proposed in July 2023 in the Annual Air Emissions

Reporting updates to include PFAS emissions in facility's reporting requirements (Reeder and Anderson 2023). This would set a standard at 0.05 tons per year for total PFAS releases from point sources (EPA 2023f).

The Office of Research and Development did not receive a completion rate in this analysis since its' three assigned objectives were not given a deadline and only determined to be ongoing actions. The office has been achieving some progress during these past two years towards achieving the initiatives. In January 2023, there has been a new webpage released under the EPA titled "PFAS Analytical Tools" that is a comprehensive database examining PFAS contamination nationwide (EPA 2023k). Although this can assist stakeholders and researchers in obtaining information about PFAS releases in the environment, this is simply a compilation of available research and does not have any requirements for nationwide monitoring or reporting. The EPA Cross-Program objectives have a 55.56% completion rate. As mentioned earlier, one objective under the category is the annual report on progress towards achieving the PFAS Strategic Roadmap goals, which was released in November 2022. Public education has also been a main goal under this category which has been accomplished through EPA webinars and stakeholder meetings (EPA 2022b). Additionally, the EPA successfully engaged with communities by hosting virtual listening sessions in each region explaining the PFAS Strategic Roadmap initiatives and progress in Spring of 2023 (EPA 2023k). See Figure 9 below for a summary of the completion rates for all EPA Offices assigned objectives under the PFAS Strategic Roadmap.

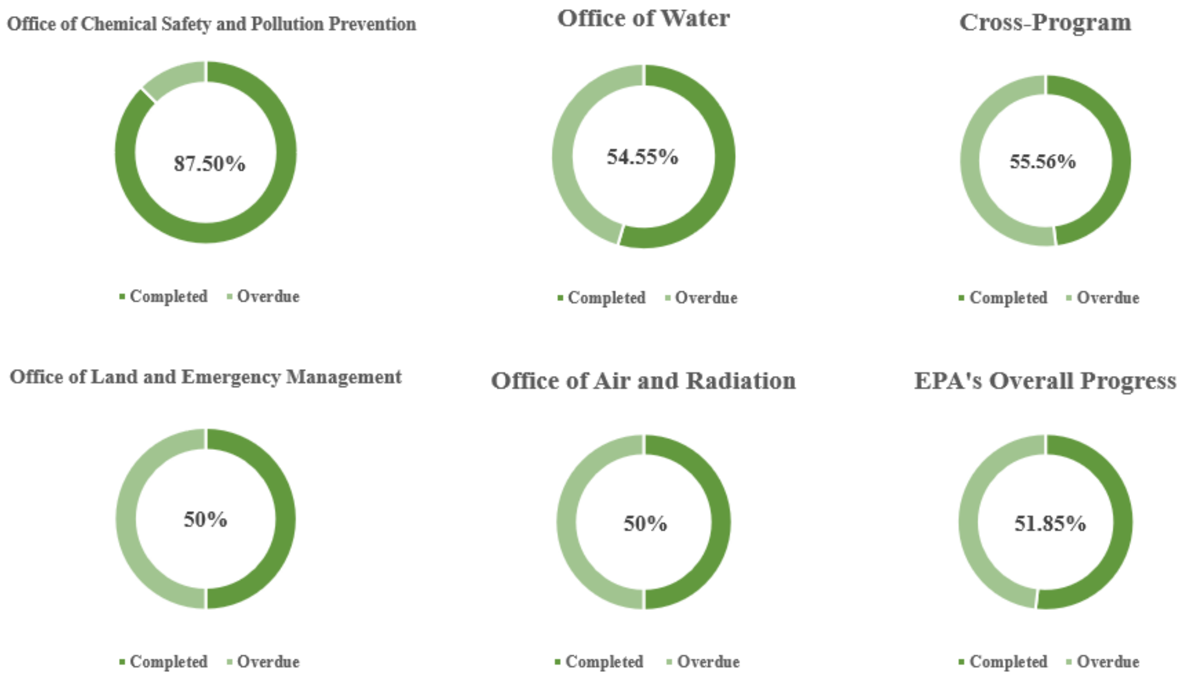


Figure 9: EPA’s PFAS Strategic Roadmap office completion rates summary

With the success experienced by the EPA’s comprehensive plan to tackle the PFAS issue, there are also many objectives that are incomplete or past due, deeming the overall progress for the EPA’s PFAS Strategic Roadmap at 51.85%. The biggest obstacle in the agency completing the outlined objectives is the commitment to science-based decision making while the science around PFAS lacks significant and historical research. While attempting to restrict and remediate PFAS contamination at the source and address legacy contamination, the need for research is delaying the process for accomplishing the final objectives. The EPA has been committed to research over the past few years but there is still much to be done to make informed decisions that will affect public health and the environment. Another obstacle is the complex issue of PFAS as a whole. There are many stakeholders involved across the PFAS domain whom make educated comments that sometimes disagree with rules proposed by the EPA. Reviewing comments and amending proposed rules can be a very time-consuming process for the agency. While the EPA continues to develop guidelines and policies for PFAS contamination, there are many legal proceedings happening currently to hold manufacturers accountable for their role in affecting public health and environmental media.

PFAS Manufacturers Lawsuits and Settlements

PFAS manufacturers are beginning to undergo major lawsuits for their contribution in contaminating nearby areas and groundwater sources with legacy PFAS. The first PFAS lawsuit was filed in 1999 against DuPont by environmental lawyer, Rob Bilott (Kluger 2023). The lawsuit came as a result of a farmer's cows dying after drinking from a stream on his property, which was adjacent to a landfill where DuPont deposited their PFAS wastes. This case took place in Parkersburg, West Virginia, in relation to the DuPont Washington Works Plant. The farmer was compensated by DuPont for his losses, but this case had a major impact on what would transpire of PFAS contamination cases against these manufacturers. Bilott continued in his pursuit against the company with the next litigation in 2001 that he filed against this same DuPont facility resulting in a class action lawsuit including 80,000 people living nearby in Parkersburg (Business and Human Rights Resource Centre 2001). These people were all affected by contaminated water with PFAS as a result of DuPont's dumping practices. The case settled in 2005 resulting in the company paying $235 million for medical monitoring for 70,000 people (Business and Human Rights Resource Centre 2001).

The legal precedent set in these early cases foreshadows what is to come for PFAS manufacturers and other polluters. There are currently thousands of cases pending in the United States directly related to PFAS contamination by individuals (Kluger 2023). Most of these will likely combine into multidistrict litigation, which will consolidate many individual cases with similar allegations against a common defendant to be heard in a single court (Kluger 2023). Most recently in June 2023, DuPont, along with their spin-off companies Chemours and Corteva, settled a case regarding public water systems in which they had to pay $1.185 billion in damages (Kluger 2023). Another major PFAS manufacturer, 3M, also reached a huge settlement in June 2023 where the company agreed to pay out money to cities and counties across the nation whose public water systems were contaminated by their PFAS wastes (Friedman and Giang 2023). This settlement cost the manufacturer $10.3 billion (Friedman and Giang 2023). In addition to individuals and local lawsuits, state attorneys general are also taking legal action against these PFAS manufacturers. Currently, there are 27 states that are suing companies for contaminating the drinking water supply and other environmental media (Safer States 2023a). It is important to emphasize again that these legal proceedings are only the beginning. As PFAS research and testing methods develop further, there will likely be many more multidistrict litigation suits and class action lawsuits to come down on these manufacturers.

Research Limitations and Areas for Future Study

With the current nature of the PFAS topic, this research suffered many limitations into the availability of comprehensive data and relevant scientific papers pertaining to the study. The environmental data used for this project was chosen due to the nationwide requirement for states to monitor for PFAS constituents in drinking water. This was the best available and consistent dataset to analyze in order to justify PFAS policies among states. However, as noted throughout this paper, the UCMR 5 data utilized is only the initial release of information to be collected during this three-year cycle. The July 2023 UCMR 5 occurrence data release only compiles approximately 7% of the complete figures. Although every state did submit data during this time, there may be a different analysis upon completion of this monitoring cycle.

There should be extensive future study into the topic of PFAS policy decisions among the federal and state governments. Complex environmental issues policy-making efforts need to be examined in order to influence future policies of similar nature. First, a similar study should be fulfilled upon the completion of the UCMR 5 data collection cycle in order to gain a full view on the extent of contamination within states and relevant policies. Further, there needs to be future areas of study pertaining to other environmental media and statutes. The most glaring of these is the discussion of CERCLA and RCRA. PFAS wastes are currently being stored in place until updated guidance is issued to dispose of these chemicals. This can create safety concerns as these wastes stockpile in areas across the United States. As discussed in Chapter 3 with the Illinois PFAS incineration ban, there needs to be scientific understanding on destruction and disposal techniques for these forever chemicals in order for the federal and state governments to enact policies based on the best available scientific information. It would be interesting to analyze comprehensive information on this topic to understand extent of contamination in regards to all viable options for disposal. Finally, the effects on human health need to be further developed in order to discern appropriate standards for PFAS constituents. As mentioned in the beginning of this research, there are currently 9,000+ chemicals with new variations still entering the market. The most efficient way to regulate these chemicals would be by identifying classes or categories of chemicals in order to provide the best protection in a logical timeframe.

Concluding Remarks

PFAS policy is a nascent topic in the environmental sciences research community as of late. It is important to analyze the motivation for policy development among federal and state governments. As shown in the micro-analysis section of Chapter 3 on the Illinois PFAS incineration ban, these decisions are sometimes purely politically motivated by elected officials and non-governmental environmental groups and lack the scientific background these final promulgations require. The macro-analysis of this paper agrees with the micro-analysis example. On a nationwide basis, perceived and actual contamination of a state does not determine whether that state takes policy actions to protect against the pollutants but rather relies solely on the majority political party running the state legislature. Although states are leading in PFAS policies when compared to the federal government, this may be premature due to the motivation behind this policy implementation. The federal government is taking time to research all areas surrounding PFAS in order to make science-based policy decisions. The proposed NPDWR for six PFAS discussed in Chapter 3 is a perfect example to illustrate this. After much groundwork to determine these safe levels of PFAS in drinking water, the proposed rulemaking was released with thorough implications regarding cost and feasibility to the public water systems which will be responsible for implementing the standards. Overall, the main goal of environmental policy should be to uphold the best protections for human health and the environment based on science. The findings in this research should be used to further study future areas of PFAS policy.

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APPENDICES

APPENDIX A

Political party delegations by state

State	Political Party
Alabama	Republican
Alaska	Democrat
Arizona	Republican
Arkansas	Republican
California	Democrat
Colorado	Democrat
Connecticut	Democrat
Delaware	Democrat
District of Columbia	Democrat
Florida	Republican
Georgia	Republican
Hawaii	Democrat
Idaho	Republican
Illinois	Democrat
Indiana	Republican
Iowa	Republican
Kansas	Republican
Kentucky	Republican
Louisiana	Republican
Maine	Democrat
Maryland	Democrat
Massachusetts	Democrat
Michigan	Democrat
Minnesota	Democrat*
Mississippi	Republican
Missouri	Republican
Montana	Republican
Nebraska	Republican
Nevada	Democrat
New Hampshire	Democrat
New Jersey	Democrat
New Mexico	Democrat
New York	Democrat
North Carolina	Democrat*
North Dakota	Republican
Ohio	Republican
Oklahoma	Republican
Oregon	Democrat
Pennsylvania	Democrat
Rhode Island	Democrat
South Carolina	Republican
South Dakota	Republican
Tennessee	Republican
Texas	Republican
Utah	Republican
Vermont	Democrat
Virginia	Democrat
Washington	Democrat
West Virginia	Republican
Wisconsin	Republican
Wyoming	Republican

Political Party governed by 2023 congressional districts within each state. Majority Republican/Democrat congressional districts was the determining factor for the state.

*: Indicates even split between majority Republican/Democrat congressional districts. Current state governor's political party was used as the determining factor for these states.

APPENDIX B

UCMR 5 data exceedance ratios by state

State	UCMR 5 Data Exceedance Ratio
Alabama	0.01503
Alaska	0.00541
Arizona	0.00315
Arkansas	0.04035
California	0.01159
Colorado	0.01699
Connecticut	0.02801
Delaware	0.09162
District of Columbia	0.00000
Florida	0.06313
Georgia	0.01633
Hawaii	0.00000
Idaho	0.00000
Illinois	0.00586
Indiana	0.00535
Iowa	0.01395
Kansas	0.00740
Kentucky	0.00601
Louisiana	0.00365
Maine	0.02186
Maryland	0.06204
Massachusetts	0.01758
Michigan	0.00183
Minnesota	0.01369
Mississippi	0.00000
Missouri	0.00108

State	UCMR 5 Data Exceedance Ratio
Montana	0.00274
Nebraska	0.00087
Nevada	0.00782
New Hampshire	0.01392
New Jersey	0.06869
New Mexico	0.01153
New York	0.01031
North Carolina	0.03815
North Dakota	0.00000
Ohio	0.01645
Oklahoma	0.00917
Oregon	0.00086
Pennsylvania	0.03185
Rhode Island	0.02625
South Carolina	0.02945
South Dakota	0.00648
Tennessee	0.00752
Texas	0.01343
Utah	0.00520
Vermont	0.00000
Virginia	0.01608
Washington	0.01331
West Virginia	0.00481
Wisconsin	0.00596
Wyoming	0.00000

UCMR 5 data exceedance ratio computed by taking the total count of PFAS exceedances within a state and dividing this by the total count of PFAS monitoring data for that state. Note: This is not complete UCMR 5 occurrence data but only the initial release of monitoring specifics released in July 2023. This will only compile about 7% of the complete occurrence data for UCMR 5 collected between years 2023-2025.

APPENDIX C

Military bases in each state

State	Military Installations	Total	Group Number
Alabama	Fort Novosel		
	Maxwell-Gunter		
		2	1
Alaska	Eielson Air Force Base		
	Fort Wainwright		
	Join Base Elmendorf- Richardson		
		3	2
Arizona	Marine Corps Air Station Yuma		
	Fort Huachuca		
	Yuma Proving Ground		
	Davis-Monthan Air Force Base		
	Luke Air Force Base		
		5	3
Arkansas	None listed	0	1
California	China Lake Naval Air Weapons Station		
	Naval Air Station Lemoore		
	Naval Air Station North Island		
	Naval Amphibious Base Coronado		
	Naval Base Coronado		
	Naval Base Point Loma		
	Naval Base San Diego		
	Naval Base Venture County		
	Marine Corps Air Ground Combat Center- Twentynine Palms		
	Marine Corps Air Station Miramar		
	Marine Corps Base Camp Pendleton		
	Marine Corps Recruit Depot San Diego		
	Fort Irwin		
	Presidio of Monterey		
	Coast Guard Training Center Petaluma		
	US Coast Guard Station San Diego		
	Beale Air Force Base		
	Edwards Air Force Base		
	Los Angeles Air Force Base		
	March Air Reserve Base		
	Travis Air Force Base		

State	Military Installations	Total	Group Number
California (continued)			
	Vandenberg Air Force Base		
		22	3
Colorado	Fort Carson		
	Buckley Air Force Base		
	Peterson Air Force Base		
	Schriever Air Force Base		
	United States Air Force Academy		
		5	3
Connecticut	Naval Submarine Base New London		
		1	1
Delaware	Dover Air Force Base		
		1	1
District of Columbia	Joint Base Anacostia-Bolling		
	Naval District Washington		
		2	1
Florida	Naval Air Station Jacksonville		
	Naval Air Station Key West		
	Naval Air Station Pensacola		
	Naval Air Station Whiting Field		
	Naval Station Mayport		
	Naval Support Activity Panama City		
	Eglin Air Force Base		
	Hurlburt Field		
	MacDill Air Force Base		
	Patrick Air Force Base		
	Tyndall Air Force Base		
		11	3
Georgia	Naval Submarine Base Kings Bay		
	Fort Gordon		
	Fort Moore		
	Fort Stewart		
	Hunter Army Airfield		
	Moody Air Force Base		
	Robins Air Force Base		
		7	3
Hawaii	Joint Base Pearl Harbor-Hickam		
	Marine Corps Bases Hawaii, Kaneohe Bay		

State	Military Installations	Total	Group Number
Hawaii (continued)			
	Schofield Barracks/Fort Shafter		
	Coast Guard Sector Honolulu		
		4	2
Idaho	Mountain Home Air Force Base		
		1	1
Illinois	Naval Station Great Lakes		
	Scott Air Force Base		
		2	1
Indiana	Grissom Air Reserve Base		
		1	1
Iowa	None listed	0	1
Kansas	Fort Leavenworth		
	Fort Riley		
	McConnell Air Force Base		
		3	2
Kentucky	Fort Campbell		
	Fort Knox		
		2	1
Louisiana	Naval Air Station Joint Reserve Base New Orleans		
	Fort Johnson		
	Barksdale Air Force Base		
		3	2
Maine	None listed	0	1
Maryland	Joint Base Andrews		
	Naval Air Station Patuxent River		
	US Naval Academy		
	Aberdeen Proving Ground		
	Fort George G. Meade		
	Coast Guard Sector Baltimore		
		6	3
Massachusetts	Fort Devens		
	Hanscom Air Force Base		
		2	1
Michigan	None listed	0	1
Minnesota	None listed	0	1
Mississippi	Naval Air Station Meridian		
	Naval Construction Battalion Center Gulfport		

State	Military Installations	Total	Group Number
Mississippi (continued)			
	Columbus Air Force Base		
	Keesler Air Force Base		
		4	2
Missouri	Fort Leonard Wood		
	Whiteman Air Force Base		
		2	1
Montana	Malmstrom Air Force Base		
		1	1
Nebraska	Offutt Air Force Base		
		1	1
Nevada	Naval Air Station Fallon		
	Area 51		
	Creech Air Force Base		
	Nellis Air Force Base		
		4	2
New Hampshire	None listed	0	
New Jersey	Joint Bae McGuire-Dix-Lakehurst		
		1	1
New Mexico	Cannon Air Force Base		
	Holloman Air Force Base		
	Kirtland Air Force Base		
		3	2
New York	Naval Support Activity Saratoga Springs		
	Fort Drum		
	Fort Hamilton		
	United States Military Academy, West Point		
		4	2
North Carolina	Marine Corps Air Station Cherry Point		
	Marine Corps Air Station New River		
	Marine Corps Base Camp Lejeune		
	Fort Liberty		
	Pope Field		
	Seymour Johnson Air Force Base		
		6	2
North Dakota	Grand Forks Air Force Base		

State	Military Installations	Total	Group Number
North Dakota (continued)			
	Minot Air Force Base		
		2	1
Ohio	Wright-Patterson Air Force Base		
		1	1
Oklahoma	Fort Sill		
	Altus Air Force Base		
	Tinker Air Force Base		
	Vance Air Force Base		
		4	2
Oregon	None listed	0	1
Pennsylvania	Carlisle Barracks		
		1	1
Rhode Island	Naval Station Newport		
		1	1
South Carolina	Joint Base Charleston		
	Naval Weapons Station Charleston		
	Marine Corps Air Station Beaufort		
	Maine Corps Recruit Depot Parris Island		
	Fort Jackson		
	Shaw Air Force Base		
		6	3
South Dakota	Ellsworth Air Force Base		
		1	1
Tennessee	None listed	0	
Texas	Naval Air Station Corpus Christi		
	Naval Air Station Joint Reserve Base Fort Worth		
	Camp Bullis		
	Fort Bliss		
	Fort Cavazos		
	Joint Base San Antonio		
	Dyess Air Force Base		
	Goodfellow Air Force Base		
	Laughlin Air Force Base		
	Sheppard Air Force Base		
		10	3

State	Military Installations	Total	Group Number
Utah	Dugway Proving Ground		
	Hill Air Force Base		
		2	1
Vermont	None listed	0	1
Virginia	Joint Expeditionary Base Little Creek-Fort Story		
	Naval Air Station Oceana		
	Naval Air Station Oceana Dam Neck Annex		
	Naval Station Norfolk		
	Joint Base Myer- Henderson Hall		
	Marine Corps Base Quantico		
	Fort Belvoir		
	Fort Gregg- Adams		
	Fort Myer		
	Joint Base Langley- Eustis		
	Coast Guard Sector Hampton Roads		
		11	3
Washington	Naval Air Staion Whidbey Island		
	Naval Base Kitsap		
	Naval Station Everett		
	Joint Base Lewis- McChord		
	Coast Guard Sector Puget Sound		
	Fairchild Air Force Base		
		6	3
West Virginia	None listed	0	1
Wisconsin	Fort McCoy		
		1	1
Wyoming	F.E. Warren Air Force Base		
		1	1

1. Group number refers to the value the state was assigned in the binomial logistical regression general linear model. National average of military bases was determined by averaging all states with at least one military base, zero values were not included in the calculation. The national average was determined to be 3.7 military bases. Group “1” refers to states with 0-2 military bases; Group “2” refers to states with 3-4 military bases; Group “3” refers to states with 5+ military bases.

2. Data was accumulated from www.military.com and includes US Army, US Navy, US Coast Guard, US Air Force, and US Marine military installations. The main ideology for exclusion/inclusion criteria for this research is based on the potential for environmental contamination through the use of AFFF. Office buildings, command center operations only, medical centers, arsenals, and school research buildings that do not involve training were all excluded from the analysis. All active military installations, including facilities which offer operational training or serve as a weapons’ testing unit were included in the analysis. Additionally, joint bases, which are two separate military branches that have combined forces in an adjacent geographical location, are only counted as one installation within that state.

APPENDIX D

UCMR 3 v. UCMR 5 Data Exceedance Ratios and Percent Change

State	UCMR 3 Data Exceedance Ratio	UCMR 5 Data Exceedance Ratio	Percent Change
Alabama	0.01405	0.01503	7%
Alaska	0.00000	0.00541	100%*
Arizona	0.00707	0.00315	-55%
Arkansas	0.00000	0.04035	100%*
California	0.00343	0.01159	238%
Colorado	0.06077	0.01699	-72%
Connecticut	0.00000	0.02801	100%*
Delaware	0.04872	0.09162	88%
District of Columbia	0.00000	0.00000	N/A
Florida	0.00571	0.06313	1006%
Georgia	0.00861	0.01633	90%
Hawaii	0.00000	0.00000	N/A
Idaho	0.00000	0.00000	N/A
Illinois	0.00065	0.00586	806%
Indiana	0.00076	0.00535	601%
Iowa	0.00000	0.01395	100%*
Kansas	0.00077	0.00740	859%
Kentucky	0.00108	0.00601	456%
Louisiana	0.00000	0.00365	100%*
Maine	0.01016	0.02186	115%
Maryland	0.00073	0.06204	8350%
Massachusetts	0.00648	0.01758	171%
Michigan	0.00070	0.00183	162%
Minnesota	0.01164	0.01369	18%
Mississippi	0.00000	0.00000	N/A
Missouri	0.00000	0.00108	100%*
Montana	0.00000	0.00274	100%*
Nebraska	0.00000	0.00087	100%*
Nevada	0.00000	0.00782	100%*
New Hampshire	0.01067	0.01392	31%
New Jersey	0.01392	0.06869	394%
New Mexico	0.00049	0.01153	2231%
New York	0.00505	0.01031	104%
North Carolina	0.00669	0.03815	470%
North Dakota	0.00000	0.00000	N/A
Ohio	0.00427	0.01645	285%
Oklahoma	0.00130	0.00917	605%
Oregon	0.00000	0.00086	100%*

State	UCMR 3 Data Exceedance Ratio	UCMR 5 Data Exceedance Ratio	Percent Change
Pennsylvania	0.01115	0.03185	186%
Rhode Island	0.00446	0.02625	488%
South Carolina	0.00072	0.02945	3991%
South Dakota	0.00312	0.00648	108%
Tennessee	0.00051	0.00752	1370%
Texas	0.00039	0.01343	3304%
Utah	0.00000	0.00520	100%*
Vermont	0.00000	0.00000	N/A
Virginia	0.00066	0.01608	2322%
Washington	0.00241	0.01331	453%
West Virginia	0.02206	0.00481	-78%
Wisconsin	0.00205	0.00596	191%
Wyoming	0.00000	0.00000	N/A

UCMR 3 occurrence data is a complete data set consisting of six PFAS from 2013-2015. Note: UCMR 5 occurrence data consists of only the initial release of monitoring specifics for the monitoring period 2023-2025. This data was published in July 2023 and consists of about 7% of the total expected data to be collected during these years. UCMR 5 occurrence data contains information about twenty-nine specific PFAS.

Both data sets were sorted to remove non-PFAS contaminants. The exceedance ratios were then calculated by taking the total count of PFAS exceedances within a state and dividing this by the total count of PFAS monitoring data for that state.

*: Indicates assumed 100% change between UCMR cycles due to beginning with a zero value in UCMR 3.

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