Strategy to Assess the Impact of Per- and Polyfluoroalkyl Substances on Drinking Water in South Carolina

Bureau of Water

South Carolina Department of Health & Environmental Control

2600 Bull Street
Columbia, South Carolina 29201

Richard Welch Jr, PE
for Strategy Development Team

Doug Kinard, PE, Director
Division of Drinking Water Protection

Mike Marcus, PhD, Chief
Bureau of Water

January 30, 2020

dhec
Healthy People. Healthy Communities.

Bureau of Water Strategy Development Team

Jim Ferguson, PG	Hydrogeologist, Drinking Water Compliance
Doug Kinard, PE	Director, Drinking Water Protection
Mike Marcus, PhD	Bureau Chief
Kyle Maurer Sr, PhD, PE	Engineer, Drinking Water Compliance (*)
Crystal Rippy	Manager, Industrial Wastewater Permitting
Richard Welch Jr, PE	Manager, Drinking Water Compliance

Internal Peer Review -- Environmental Affairs

Ann Clark	Bureau of Water
Rob Devlin	Bureau of Water
Stacey French, PE	Bureau of Land and Waste Management
Chuck Gorman, PG	Bureau of Water
Jennifer Hughes	Bureau of Water
Sandra Snyder	Bureau of Land and Waste Management
Ken Taylor, PG	Bureau of Land and Waste Management

External Peer Review -- Drinking Water Technical Advisory Council

David Baize	South Carolina's Water Associations (**)
David Bereskin	Greenville Water (**)
Jeff Boss	Greenville Water (**)
Mark Cline	Charleston Water System (**)
Clay Duffie	Mount Pleasant Waterworks (**)
Charlie Gray	Chesterfield Rural Water (**)
Kin Hill	Charleston Water System (**)
Charles Hilton	Breezy Hill Water & Sewer (**)
Tricia Kilgore	Beaufort-Jasper Water & Sewer Authority (**)
Jill Miller	South Carolina Rural Water Association (**)
Jeff Phillips	Greenville Water
Dwayne Porter, PhD	University of South Carolina
Chris Rasco	Powdersville Water
Geoff Scott, PhD	University of South Carolina (**)
Clint Shealy	City of Columbia
Dyke Spencer	Powdersville Water (**)
Ken Tuck	Spartanburg Water
Bobby Walden	Spartanburg Water
John Westcott	Spartanburg Water (**)
Fred Yandle	South Carolina American Water Works Association

(*) Present affiliation: Office of Regulatory Staff, S.C. Public Service Commission
(**) DWTAC member who participated in review/discussion of Strategy

TABLE OF CONTENTS

Page Intentionally Left Blank

ACRONYMS USED

3M	3M Company
AFFF	Aqueous Film-Forming Foam
AOC	Airport Operating Certificate
ARFF	Aircraft Rescue and Firefighting
ATSDR	Agency for Toxic Substances and Disease Registry
BLWM	Bureau of Land and Waste Management (SCDHEC)
BOW	Bureau of Water (SCDHEC)
C&D	Construction and Demolition
CASRN	Chemical Abstract Services Registry Number
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DOD	US Department of Defense
DOE	US Department of Energy
FP	Fluoropolymer
FR	Federal Register
FY	Fiscal Year
GAC	Granular Activated Carbon
HA	Health Advisory
ITRC	Interstate Technology Regulatory Council
MCL	Maximum Contaminant Level
MRL	Method Reporting Limit
MSW	Municipal Solid Waste
ND	No Discharge
NHANES	National Health and Nutrition Examination Survey
NPDES	National Pollutant Discharge Elimination System
OCPSF	Organic Chemical, Plastics and Synthetic Fibers
ppt	Parts per Trillion
PFAA	Perfluoroalkyl acid
PFAS	Per- and Polyfluoroalkyl Substance
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PWS	Public Water System(s)
RCRA	Resource Conservation and Recovery Act
SCDHEC	South Carolina Department of Health and Environmental Control; the Department
SCSFA	South Carolina State Firefighters' Association
SDWA	Safe Drinking Water Act
SIC	Standard Industrial Classification
SRS	Savannah River Site
UCMR	Unregulated Contaminant Monitoring Rule
USEPA	US Environmental Protection Agency
WHPA	Wellhead Protection Area
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

LIST OF TABLES

EXECUTIVE SUMMARY

Per- and polyfluoroalkyl substances are a complex family of more than 4,000 commercially-available, manmade chemicals, the earliest of which were produced in the late 1940s. Per- and polyfluoroalkyl substances have been used in coatings for textiles, paper products, metal plating, cookware, and to formulate some firefighting foams, among other things. The unique chemical properties of per- and polyfluoroalkyl substances make their environmental fate and transport complex and difficult to predict. Their effect on human and environmental health are relatively unknown, but current science suggests there may be negative health effects from long-term exposure. The purpose of this Strategy is to guide the South Carolina Department of Health and Environmental Control's efforts to evaluate the impact of those chemicals on the State's drinking water.

The United States Environmental Protection Agency established a drinking water lifetime health advisory [*i.e.,* consuming four (4) liters of water per day for 70 years] for perfluorooctanoic acid and perfluorooctanesulfonic acid on May 25, 2016. This health advisory is 70 parts per trillion for either of those individual chemicals or for both in combination. Health advisories are non-regulatory guidance; they are not enforceable federal standards. A health advisory identifies the concentration of a substance in drinking water at or less than which adverse health effects are not anticipated to occur over a lifetime of exposure. It is protective of most typical water users including pregnant/nursing women, young children and the elderly.

In February 2019, the United States Environmental Protection Agency published its Action Plan that described their approach to: (a) identify and understand per- and polyfluoroalkyl substances; (b) address current per- and polyfluoroalkyl substance contamination; (c) prevent future contamination; and, (d) effectively communicate with the public. These actions should assist the development of more technical information to better inform regulatory decisions on these emerging contaminants.

There are no current facilities in South Carolina known to produce per- and polyfluoroalkyl substances. However, due to their unique chemical properties, per- and polyfluoroalkyl substances may be used in the production of other goods at industries throughout South Carolina and the Nation. Per- and polyfluoroalkyl substances are a key ingredient in Class B firefighting foams that are used to extinguish flammable liquid and gas fires. The presence of per- and polyfluoroalkyl substances in many consumer items [*e.g.,* nonstick cookware, food packaging (microwave popcorn bags, fast food wrappers, sliced cheese wrappers, pizza boxes), stain-resistant carpets and fabrics and water-resistant clothing. paints, varnishes and sealants, cosmetics, dental floss fire-fighting foams] further increases public exposure to these chemicals at home and throughout the environment.

The Interstate Technology Research Council describes the four most probable, significant per- and polyfluoroalkyl substance sources as: fire training/fire rescue sites, industrial sites, landfills and wastewater treatment plants. These sectors and their presence in South Carolina are described in Part III of this document.

Recent studies regarding per- and polyfluoroalkyl substance contamination and institutional knowledge of drinking water systems were used to evaluate the more probable per- and polyfluoroalkyl substance sources throughout South Carolina and the potential vulnerability of a given drinking water source. This document presents a Strategy for acquisition of empirical data to evaluate: (1) the presence of per- and polyfluoroalkyl substances in South Carolina drinking water and (2) the portion of the population that may be exposed to per- and polyfluoroalkyl substances in drinking water. This information will lead to a better understanding of potential public health concerns from per- and polyfluoroalkyl substance exposure and more informed decisions regarding the need to regulate per- and polyfluoroalkyl substances in drinking water and the environment.

I. INTRODUCTION

A. What are PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a complex family of more than 3,000 commercially-available, manmade chemicals, the earliest of which were produced in the late 1940s (Wang *et al.* 2017). PFAS are used to make products that resist heat, oil, stains, grease and water. They are a common and widespread chemical residual of modern society. The nomenclature for unique PFAS analytes tends to be long and complex. A list of the quantifiable PFAS measured using the United States Environmental Protection Agency (USEPA) Methods 533 and 537.1, their acronyms (that will be used throughout this document) and their chemical abstract services registry number (CASRN) is provided in Table 1.

As awareness has grown regarding the potential public health implications of these chemicals, various entities have taken steps to reduce production and pollution. For example, 3M Company (3M) announced in 2000, and completed in 2002, that it would voluntarily phase out and find substitutes for PFOS chemistry used to produce a range of products in the United States (USEPA 2000). At that time 3M was the sole US manufacturer of PFOS. Also, in 2006, eight (8) major producers in the U.S. agreed to phase out production of PFOA and PFOA-related chemicals by 2015. Nonetheless, PFAS have been found throughout the environment at concentrations that are concerning to some health professionals. As a result, PFAS have been and are the focus of many studies on the presence in the environment and associated effect(s) on human and environmental health.

Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) were the two most commonly-produced and are the most commonly-studied of the PFAS analytes. Generally, chemicals in the PFAS class:

- do not occur naturally yet are widespread in the environment because of their broad uses
- are found in people, wildlife and fish world-wide
- are stable and do not break down easily in the environment (they are persistent)
- can build up in biological tissues over time (people, wildlife, fish) if exposure continues (they bioaccumulate)

B. Sources of PFAS

PFAS are man-made, so there are no natural sources in the environment. PFAS can be found near areas where they are manufactured; in some industrial applications (*e.g.*, electroplating, textiles, pulp and paper); and/or, in some manufactured products. Although PFOA and PFOS are no longer manufactured in the U.S., some consumer and industrial products may still contain them as well as other PFAS analytes. Common products where PFAS was used and may still be used in their production include some:

- nonstick cookware
- food packaging *(e.g.,* microwave popcorn bags, fast food wrappers, sliced cheese wrappers, pizza boxes)
- stain-resistant carpets and fabrics
- water-resistant clothing
- paints, varnishes and sealants
- cosmetics
- dental floss
- firefighting foams

Exposure to PFAS by way of drinking water occurs only if the source water supply has been contaminated by a PFAS source such as a PFAS manufacturer, some types of wastewater treatment facilities, landfills or firefighter training facilities. The preponderance of human exposure to PFAS is through use of the many commercial products in which PFAS are present.

Table 1. List of Quantifiable PFAS by USEPA Methods 533 and 537.1

Analyte	Acronym	CASRN	Method 533	Method 537.1
Hexafluoropropylene oxide dimer acid	HFPO-DA	13252-13-6	√	√
N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	2991-50-6	--	√
N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	2355-31-9	--	√
Perfluorononanoic acid	PFNA	375-95-1	√	√
Perfluorodecanoic acid	PFDA	335-76-2	√	√
Perfluorododecanoic acid	PFDoA	307-55-1	√	√
Perfluoroheptanoic acid	PFHpA	375-85-9	√	√
Perfluorohexanoic acid	PFHxA	307-24-4	√	√
Perfluorohexanesulfonic acid	PFHxS	355-46-4	√	√
Perfluorononanoic acid	PFNA	375-95-1	√	√
Perfluorooctanoic acid	PFOA	335-67-1	√	√
Perfluorooctanesulfonic acid	PFOS	1763-23-1	√	√
Perfluorotetradecanoic acid	PFTA	376-06-7	--	√
Perfluorotridecanoic acid	PFTrDA	72629-94-8	--	√
Perfluoroundecanoic acid	PFUnA	2058-94-8	√	√
11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	763051-92-9	√	√
9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid	9Cl-PF3ONS	756426-58-1	√	√
4,8-dioxa-3H-perfluorononanoic acid	ADONA	919005-14-4	√	√
Perfluorobutanesulfonic acid	PFBS	375-73-5	√	√
Perfluorobutanoic acid	PFBA	375-22-4	√	--
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7	√	--
Perfluoroheptanesulfonic acid	PFHpS	375-92-8	√	--
Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5	√	--
Perfluoro-3-methoxyproponoic acid	PFMPA	377-73-1	√	--
Perfluoropentanoic acid	PFPeA	2706-90-3	√	--
Perfluoropentane sulfonic acid	PFPeS	2706-91-4	√	--
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6	√	--
1H, 1H, 2H, 2H-Perfluorohexane sulfonic acid	4:2FTS	757124-72-4	√	--
1H, 1H, 2H, 2H-Perfluorooctane sulfonic acid	6:2FTS	27619-97-2	√	--
1H, 1H, 2H, 2H-Perfluorodecane sulfonic acid	8:2FTS	39108-34-4	√	--

C. Environmental Fate and Transport

The class-specific chemical properties of PFAS make their environmental fate and transport complex and difficult to predict. Some PFAS transform into perfluoroalkyl acids (PFAA), such as PFOA and PFOS, in the environment through various biotic and abiotic processes (ITRC 2018b). PFAA are mobile, persistent, bioaccumulative and are not known to break down under ambient environmental conditions (NTP 2016). Much of the research on the fate and transport of PFAS up to this point has focused on PFAA.

Transport in groundwater is typically driven by advection, *i.e.,* moving at the general speed and direction of groundwater flow (ITRC 2018b). Other phenomena, such as sorption to various media (Guelfo and Higgins 2013) and the preference of PFAS to mobilize at the air-water interface (Krafft and Riess 2015) make predicting their transport difficult, particularly in unsaturated conditions where advection may be retarded (Brusseau 2018). Downward leaching can also significantly impact transport during unsaturated conditions, particularly in situations involving surface-applied materials containing PFAS (Sepulvado *et al.* 2011).

D. Human Health Effects

The US Centers for Disease Control and Prevention (CDC) has found four (4) PFAS (PFOS, PFOA, PFNA and PFHxS) in the blood serum of nearly all Americans tested through the National Health and Nutrition Examination Survey (NHANES) since 1999 (CDC 2019). A temporal review of the NHANES data shows that the average concentration of PFAS in blood serum has steadily declined since 1999, but the ubiquitous presence of these PFAS in humans was noteworthy and has raised potential health outcome concerns.

The CDC stresses that finding a measurable amount of PFAS in blood serum does not imply that a certain level of PFAS exposure will cause an adverse health effect. However, because such a high percentage of the population is exposed to and bioaccumulates PFAS, a better understanding of the human health impacts of PFAS is needed to determine if the presence of these chemicals in humans is a significant health concern.

The Agency for Toxic Substances and Disease Registry (ATSDR) has reported that although specific human health impacts of PFAS are uncertain and more research is needed (ATSDR 2017), some studies have suggested that certain PFAS may:

- affect growth, learning, and behavior of infants and older children
- lower a woman's chance of getting pregnant
- interfere with the body's natural hormones
- increase cholesterol levels
- affect the immune system
- increase the risk of cancer (PFOA)
- thyroid hormone disruption (PFOS)

E. Ecological Health Effects

The South Carolina Department of Health and Environmental Control (the Department) is the regulatory agency authorized by USEPA to implement and manage promulgated federal regulations for the protection of environmental quality in the State. The apparent ubiquitous nature of PFAS throughout the environment implies that living organisms have been and are, to varying extents, routinely exposed to some level of PFAS. New-generation analytical chemistry tools now present opportunities to detect and quantify PFAS (and other analytes of emerging concern) heretofore unachievable. However, much less is known about either the individual or combined (*i.e.,* interactive) toxicity of various PFAS at environmentally-relevant concentrations (Ahrens and Bundschuh 2014).

PFAS can bioaccumulate in the environment potentially leading to both acute and chronic health effects on living organisms (Giesy *et al.* 2010; Ding and Peijnenburg 2013). For example, the survival, growth and emergence of *Chironomus tentans* (midges) were found to be inhibited by 50% at PFOS exposures on the order of 100,000 (10^5) parts per trillion (ppt) (MacDonald *et al.* 2004). However, the authors noted that this was approximately two (2) orders of magnitude greater than those concentrations typically observed in aquatic environments. The bioaccumulation and subsequent elimination of PFAS by living organisms has been shown to depend on the species, gender and reproductive status of a given individual (Lee and Schultz 2010; Sharpe *et al.* 2010).

A review of current research on the effects of PFAS in aquatic environments noted a lack of research on multi-generation PFAS exposure and how the transfer of PFAS through food webs may affect ecotoxicity (Ahrens and Bundschuh 2014). Species-specific bioaccumulation of PFAS, thence entry into the human food chain is important for human health protection because humans consume meats, fish and seafood, vegetation and other plant- and animal-derived products throughout their lifetime. More knowledge on exposure point/pathway dynamics and food web transport dynamics is important for a better understanding of the environmental ramifications of PFAS exposure.

The Department will monitor future research as it pertains to environmental toxicity. At this time, the limited national regulatory guidance regarding health implications are limited to the USEPA Health Advisory (HA) for PFOA and PFOS in drinking water for humans (see Part II.A). The path forward detailed herein focuses on evaluation of public health protection relative to PFAS from the drinking water exposure pathway.

F. Purpose of Strategy

As with a number of other states, there are unknowns concerning the presence of PFAS throughout South Carolina, including source location, strength, coverage and proximity to drinking water sources. The purpose of this Strategy is to establish a methodical and rational process, based on the current state of accumulated knowledge, for the evaluation of PFAS impact on drinking water in the State. The Strategy identifies and accounts for various risk components that accumulate into a vulnerability assessment for drinking water sources. This Strategy then cascades the water supplies into succeeding levels of decreasing (apparent) risk and then uses this to establish sampling and analysis priorities.

The Department's Bureau of Water (BOW) will test for PFAS in drinking water sources to determine:

- the presence and concentrations of the quantifiable PFAS under USEPA Methods 533 and 537.1
- whether PFOA and PFOS are present at a combined concentration greater than the USEPA HA of 70 ppt

Special Note:

The BOW recognizes the importance and need to assess surface waters for ecological health impacts from PFAS as well as uptake and bioaccumulation by organisms that may be consumed by the public (*e.g.,* fish, crabs, oysters and clams). This element of the BOW's statewide ambient surface waters PFAS assessment will be addressed subsequent to the implementation of the drinking water assessment described herein. The conceptual framework and approach proposed in California will be used as one of the guidances, where adaptable and applicable to the South Carolina environment, in establishing the surface waters assessment strategy (Maruya *et al.* 2014, Anderson *et al.* 2012).

II. REGULATORY OVERVIEW AND STATUS

A. The USEPA Public Health Advisory

Public Health Advisories are developed to assist federal, state, tribal and local officials and managers of drinking water systems protect public health. They are non-regulatory technical guidance; *i.e.*, they are not legally-enforceable federal standards. A drinking water HA is intended to identify the concentration of an analyte less than which adverse health effects are not anticipated to occur over a lifetime of exposure based on current knowledge about the analyte. In other words, if an analyte concentration in drinking water is greater than a HA, it cannot be stated with confidence that there will not be a negative health impact due to long-term exposure.

USEPA established a lifetime HA of 70 ppt for discrete or combined concentrations of PFOA and PFOS via notice in the Federal Register (FR) on May 25, 2016 (81 FR 33250). A HA is just that, an advisory. It is not an enforceable regulatory standard as is a primary drinking water standard (also called a *Maximum Contaminant Level*, or MCL) under the Safe Drinking Water Act (SDWA). The HA for PFOA and PFOS is protective of most typical water users including pregnant/nursing women, young children and the elderly.

USEPA is currently evaluating the need for a nationwide MCL for PFOA and PFOS (see Section II.C). Some individual states have established regulatory, advisory and/or guidance values for various PFAS while others are evaluating the need for state-specific regulatory, advisory and guidance values [see Section II.E] (ITRC 2019).

B. Unregulated Contaminant Monitoring

In 1996, amendments to the SDWA known as the Unregulated Contaminant Monitoring Rule (UCMR) required that, once every five (5) years, USEPA issue a new list of no more than 30 unregulated contaminants to be monitored by public water systems (PWS) throughout the United States. There have been four (4) UCMR contaminant lists up to this point:

- UCMR 1 (64 FR 50556) monitored 26 contaminants between 2001 and 2003;
- UCMR 2 (72 FR 367) monitored 25 contaminants between 2008 and 2010;
- UCMR 3 (77 FR 26071) monitored 30 contaminants between 2013 and 2015; and,
- UCMR 4 (81 FR 92666) will monitor 30 contaminants between 2018 and 2020.

During UCMR 3, six (6) PFAS were monitored at 4,920 PWS nationwide (USEPA 2017), the results of which are summarized in Table 2.

Table 2. UCMR 3 Nationwide PFAS Data Summary from Public Water Systems

PFAS	MRL[A] (ppt)	No. PWS with result >MRL	% PWS with result >MRL	No. PWS with result >HA[B]	% PWS with result >HA[B]
PFOS	40	95	1.9	46	0.9
PFOA	20	117	2.4	13	0.3
PFNA	20	14	0.3	NA[C]	NA[C]
PFHxS	30	55	1.1	NA[C]	NA[C]
PFHpA	10	86	1.7	NA[C]	NA[C]
PFBS	90	8	0.2	NA[C]	NA[C]

A.MRL = Method Reporting Limit; ppt = parts per trillion

B. HA = USEPA Health Advisory (70 ppt for PFOA, PFOS or ΣPFOA & PFOS)

C. NA = Not applicable because no current HA for specified PFAS

In South Carolina under UCMR 3, the Department conducted testing for the six (6) specified PFAS at all public water systems that served greater than 10,000 people and at some small systems randomly selected by USEPA. The UCMR 3 results for the State were:

- A total of 498 samples from 82 PWS were collected and analyzed.
- Of those 498 samples, one (1) sample from the Woodruff-Roebuck Water District (PWS SC4220007) returned detections of 12 ppt for PFHpA and 24 ppt for PFOA.
- The Department conducted three (3) subsequent follow-up sample events at that system; all follow-up results were non-detects.
- The noted detections did not exceed the USEPA HA of 70 ppt PFOA and PFOS (separately or in sum)

UCMR 3 included a small fraction of PWS; therefore, this does not mean that PFAS exposure in drinking water is necessarily limited to one (1)% to two (2)% of PWS. In Michigan, a total of 92 PWS were sampled for PFAS during UCMR 3, two (2) of which were found to contain PFOS in at least one (1) sampling event (USEPA 2017). Since then, the Michigan Department of Environment, Great Lakes and Energy commissioned a 2018 Statewide PFAS Sampling Program of community and select non-community water supplies. This effort resulted in 1,741 facilities sampled and found at least one (1) PFAS in 118 facilities (approximately 10%), two (2) of which contained PFOA and PFOS greater than the USEPA HA of 70 ppt (AECOM 2019).

C. USEPA PFAS Action Plan

In February 2019, USEPA published its PFAS Action Plan that described the Agency's approach to: identify and understand PFAS; address current PFAS contamination; prevent future contamination; and, effectively communicate with the public about PFAS (USEPA 2019a). The Action Plan details concerns and challenges and outlines short- and long-term actions USEPA is taking or will take to address these concerns and challenges.

In addition to actions towards improving the understanding, cleanup, and communication of PFAS, USEPA is targeting specific actions involving drinking water, such as:

- proposing a national drinking water regulatory determination on PFOA and PFOS (this proposal, as yet not public, was submitted to the Office of Management and Budget by USEPA on December 4, 2019);
- expanding analytical methods to accurately test for PFAS in drinking water and other media (USEPA announced the addition of EPA Method 533 on December 19, 2019; allows for testing of 11 short-chain [chains of four (4) to 12 carbons] PFAS;
- incorporating the latest research results for additional PFAS into USEPA's online drinking water treatability database;
- developing toxicity values for additional PFAS;
- utilizing newer analytical methods to detect more PFAS and at lower MRLs during the next UCMR monitoring cycle; and,
- building an interactive map that displays publicly-available data on potential PFAS sources and occurrence.

As of the release date of this Strategy, the present status of USEPA's Action Plan commitments can be found at: https://www.epa.gov/newsreleases/epa-moves-forward-key-drinking-water-priority-under-pfas-action-plan

In September 2019, as follow-on to delivery of commitments under the Action Plan, USEPA awarded grants to eight (8) organizations *to expand the understanding of the environmental risks posed by per- and poly-fluoroalkyl substances (PFAS) in waste streams and identify practical approaches to manage the potential impacts as PFAS enters the environment.* (https://www.epa.gov/newsreleases/epa-awards-6-million-research-potential-environmental-impacts-pfas-substances-waste).

Those organizations and their scopes of inquiry are:

- **New York State Department of Health - Health Research Inc., Menands, N.Y.** – to build a dataset by analyzing samples from approximately 150 landfills in the State of New York. This data will be used to understand the types and concentrations of PFAS that are found in and around landfills, as well as the key landfill attributes that contribute to release of PFAS.
- **North Carolina State University, Raleigh, N.C.** – to collect landfill gas (LFG) samples from over 400 landfills across the U.S. to determine if PFAS from LFG is a significant source of PFAS released into the atmosphere.
- **University of Florida, Gainesville, Fla.** – to study the role of waste type, management strategies, and treatment methods on the occurrence, source and fate of PFAS in landfills. The study will identify the sources of PFAS compounds in the current US domestic waste stream using laboratory-scale batch leaching, and landfill simulation studies.
- **Clemson University, Clemson, S.C.** – to examine the chemical process for the destruction of PFAS in leachate and groundwater. This project will assess degradation kinetics, test hypothesized process modifications, and conduct trials of leachate treatment.
- **Purdue University, West Lafayette, Ind.** – to develop methods to decrease PFAS concentrations in both municipal wastewater treatment plant effluent and sludge. The study will determine the technical and economic feasibility of using a treatment approach consisting of nanofiltration followed by electrochemical oxidation.
- **Texas A&M AgriLife Research, College Station, Texas** – to investigate the feasibility of electron beam technology for the destruction of PFAS compounds during the remediation of groundwater, wastewater, sewage sludges, and soils.
- **Texas Tech University, Lubbock, Texas** – to identify and quantify the occurrence of PFAS in landfill leachate, investigate the fate of PFAS passing through typical landfill liner systems, and test the ability to break down PFAS in landfill leachate using soundwaves.
- **University of North Dakota, Grand Forks, N.D.** – to develop practical strategies for removing legacy and emerging PFAS from leachate and groundwater by studying the adsorption, desorption, and biodegradation of PFAS and precursor compounds in landfills.

D. The Department's Response to USEPA PFAS Action Plan

The BOW welcomed the actions announced by USEPA to address PFAS and agrees with USEPA that the development of more technical information is necessary so that defensible science informs regulatory decisions on this class of analytes. USEPA actions are a step in the right direction towards further protecting and promoting the health of the public and the environment. The Department will remain engaged at the national level and with stakeholders on this important issue.

As USEPA implements their Action Plan, the BOW will continue to:

- focus on source water protection as the key to preservation of quality drinking water;
- protect South Carolina's waters for fishable/swimmable uses and for healthy and balanced indigenous aquatic communities; and,
- follow the science-based progress in knowledge about PFAS to make informed decisions regarding the health of the public and environment.

E. Other State Approaches

Because of the heightened focus in media and among some segments of the population and the unsettled regulatory climate due to absence of an integrated nationwide regulatory framework approach, some states have taken various steps to address and/or regulate PFAS (Table 3). Not surprisingly, the chosen paths do not

align with each other. Consequently, this fragmentation leads to further doubt and concern among citizens over proper and equitable health and environmental protection.

Table 3. State Actions on Numeric Limits and Guidances for PFAS in Drinking Water

State	Action	Analyte	Concentration (ppt)
California	Interim Response Level	Σ PFOA+PFOS	70
	Notification Level	PFOA	5.1
		PFOS	6.5
Connecticut	Action Level	Σ PFOA+PFOS+PFNA+PFHxS+PFHpA	70
Massachusetts	Proposed Groundwater Cleanup Standard and Drinking Water MCL Process Initiation	Σ PFOA+PFOS+PFNA+PFHxS+PFHpA+PFDA	20
Michigan	Proposed Drinking Water MCLs	PFOA	8
		PFOS	16
		PFNA	6
		PFHxS	51
		PFBS	420
		PFHxA	400,000
		GenX	370
Minnesota	Health Based Guidance Value (HBV) for Water	PFOA	35
		PFOS	15
	(Surrogate of PFOS HBV)	PFHxS	47
New Hampshire	MCL	PFOA	12
		PFOS	15
		PFHxS	18
		PFHA	11
New Jersey	MCL	PFNA	13
		PFOA	14
		PFOS	13
New York	MCL Rulemaking Underway	PFOA	10
		PFOS	10
North Carolina	Health Advisory	GenX	140
Vermont	Health Advisory	Σ PFOA+PFOS+PFNA+PFHxS+PFHpA	20

Source: https://www.asdwa.org/pfas/

III. POTENTIAL PFAS SOURCES IN SOUTH CAROLINA

There are no current facilities in South Carolina known to manufacture PFAS or fluoropolymers (FP). However, due to their unique chemical properties, PFAS or FP may be used in the production of other goods at industries throughout South Carolina. PFAS are also a key ingredient in certain firefighting foams that are used to extinguish high-hazard fires. The presence of PFAS in many consumer items further increases exposure to these chemicals at home and the chemicals' availability throughout the environment as waste products. For example, PFAS have been used in pesticides and herbicides (ITRC 2017).

The Interstate Technology Research Council (ITRC) describes the four (4) major PFAS sources: fire training/fire rescue sites, industrial sites, landfills and wastewater treatment plants (WWTP) (ITRC 2018b). These sectors and their presence in South Carolina are described below. Although not an exhaustive compilation of all potential PFAS sources throughout South Carolina, these four (4) main source categories likely address the more-probable sources based on currently-available information.

A. Fire Training/Fire Rescue Sites

Aqueous film-forming foam (AFFF) has been used since the late 1960s to fight high-hazard flammable liquid fires by producing an aqueous film that effectively covers and extinguishes the flame and prevents re-ignition (ITRC 2018a). Typical locations where AFFF might be or have been used include:

- chemical plants
- flammable liquid storage and processing facilities
- merchant operations (oil tankers, offshore platforms)
- municipal services (fire departments, firefighting training centers)
- oil refineries, terminals, and bulk fuel storage farms
- aviation operations (aircraft rescue and firefighting, hangars)
- military facilities

AFFF is commonly used for firefighting training, particularly at military facilities, airports and firefighting training facilities. As such, these locations are individually discussed below.

<u>Military and Other Federal Facilities</u>

Based on the well-documented history of AFFF use at Department of Defense (DOD) facilities, the US Air Force began investigating and addressing PFAS contamination in 2014. Since then, the other branches of the military have followed suit and taken steps to detect and address PFAS contamination at their facilities. As of December 31, 2016, the DOD had spent over $200 million on PFOA and PFOS sampling, analysis and cleanup at various military facilities (DOD 2017).

DOD facilities in South Carolina that operated during the time that PFAS may have been used are listed in Table 4. Preliminary Assessments to determine whether AFFF foam was used at a given facility have been completed by the facilities for all but one (1) of the DOD facilities in Table 4. The remaining facility is scheduled to have its Preliminary Assessment/Site Investigation completed in fiscal year (FY) 2020. For those facilities where AFFF is known to have been used, more in-depth site investigations have been or will be performed by the facilities to determine the extent of environmental contamination that may have occurred.

South Carolina is also home to a large Department of Energy (DOE) facility, the Savannah River Site (SRS). This facility was constructed in the 1950's to produce the basic materials used in the fabrication of nuclear weapons. Through recent conversations with SRS staff, it was noted that AFFF had been used at SRS for fire training

activities. The BOW does not yet know the extent, duration and frequency of those activities. The DOE is in the process of procuring a sampling team to evaluate PFAS at SRS.

Table 4. DOD and DOE Facilities in South Carolina

Facility Name	Owner	City	Active/ Inactive	PFAS Present at Site?[A]
Charleston Naval Complex	Navy	Charleston	Inactive	TBD[B]
Fort Jackson	Army	Columbia	Active	TBD[C]
Joint Base Charleston - Air	Air Force	Charleston	Active	Confirmed
Joint Base Charleston - Weapons	Air Force	Charleston	Active	No Potential[D]
Marine Corps Air Station	Marines	Beaufort	Active	TBD[E]
Marine Corps Recruit Depot	Marines	Port Royal	Active	TBD[F]
McEntire Joint National Guard Base	Air National Guard Bureau	Sumter	Active	Confirmed
Myrtle Beach Air Force Base	Air Force	Myrtle Beach	Inactive	Confirmed
North Auxiliary Airfield[G]	Air Force	Orangeburg	Active	Confirmed
Poinsett Electronic Combat Range	Air Force	Wedgefield	Active	No Potential[D]
Shaw Air Force Base	Air Force	Sumter	Active	Confirmed
Savannah River Site	DOE	Jackson	Active	TBD[H]

A. status of DOD facilities current as of September 13, 2019, per BLWM
B. awaiting results of groundwater monitoring during Site Investigation
C. Preliminary Assessment/Site Investigation planned for FY 2020
D. no potential AFFF release areas identified in DOD Preliminary Assessment at Weapons site
E. Preliminary Assessment currently under review
F. Site Investigation planned
G. associated with Joint Base Charleston - Air
H. the DOE is in the process of procuring a sampling team to evaluate PFAS at the site

Airports

Title 14 Code of Federal Regulations (CFR), Part 139 (14 CFR Part 139) requires an Airport Operating Certificate (AOC) for certain US airports serving scheduled flights with more than nine passenger seats and unscheduled flights with at least 31 passenger seats. All Part 139 certified airports must have aircraft rescue and firefighting (ARFF) capabilities, which includes the proper equipment (*e.g.,* AFFF), personnel, and training.

Part 139 certified airports are indexed based on a combination of the length of the aircrafts that utilize the airport and the average number of daily departures for said aircraft lengths. The index values range from A (smallest aircrafts) to E (largest aircrafts). Airports routinely serving larger aircrafts are required to demonstrate higher ARFF capabilities. As such, Index E airports will likely have significantly more AFFF onsite than Index D, and so-on down to Index A which may not have AFFF onsite at all. Many small, rural airports are not required to have an AOC or ARFF capabilities through 14 CFR Part 139.

Regardless of index, ARFF personnel are required to receive recurrent instruction every 12 consecutive calendar months and must participate in at least one (1) live-fire drill prior to initial performance of ARFF duties and every

12 consecutive calendar months thereafter. The training does not have to be at the specific airport; it can be at a military facility or other firefighting training facility that offers ARFF training. For example, the South Carolina Fire Academy is a Federal Aviation Administration Regional ARFF fire training center.

The eight (8) Part 139 certified airports in South Carolina are listed in Table 5 by descending ARFF Index, then Class, then alphabetically. The higher (*i.e.*, C vs. B vs. A) the ARFF index, the more likely an airport is to have more AFFF opportunity.

Table 5. 14 CFR Part 139-Certified Airports in South Carolina

Airport Name (ID)	City	PART 139 Class	ARFF Index
Charleston International (CHS)[A]	Charleston	Class I	C
Greenville-Spartanburg International (GSP)	Greer	Class I	C
Myrtle Beach International (MYR)	Myrtle Beach	Class I	C
Columbia Metropolitan (CAE)[B]	Columbia	Class I	B
Florence Regional (FLO)	Florence	Class I	A
Hilton Head (HXD)	Hilton Head Island	Class I	A
Anderson Regional (AND)	Anderson	Class IV	A
Donaldson Center (GYH)[C]	Greenville	Class IV	A

A. Charleston International Airport is adjacent to Joint Base Charleston
B. South Carolina Fire Academy was previously located near Columbia Metropolitan Airport
C. prior to 1963, this facility was owned by the DOD under the name Donaldson Air Force Base.

Firefighting Training Facilities

According to the South Carolina State Firefighters Association (SCSFA) member directory, nearly 500 individual fire departments make up the membership of the association (SCSFA 2019). The total number of fire departments in South Carolina is certainly larger, as not all fire departments are members of the SCSFA. Many of these fire departments could have AFFF stored onsite, but its use for routine training activities at a given fire department is not currently known by the BOW.

The South Carolina Fire Academy's current facility, covering 208 acres just north of Columbia, South Carolina, is declared to be the *most comprehensive* state fire training facility in the nation (SC Fire Academy 2019). The facility is one (1) of a select few in the nation to feature state-of-the-art, computerized, propane-fueled props. ARFF training and training for the use of firefighting foam is advertised as two (2) of the training opportunities at the facility. Based on the expense and complexity of AFFF training, it is plausible that most, if not all, firefighters in South Carolina could be trained to use AFFF at the South Carolina Fire Academy. Given the size, longevity and training resources of the facility, this site is a plausible PFAS-source candidate.

The BOW's overall knowledge of other current and former firefighting training facilities in South Carolina is lacking at this time, but collaboration with the Office of the State Fire Marshal may lead to the identification of additional sites of interest. Before moving to its current location, the South Carolina Fire Academy was located near the Columbia Metropolitan Airport. Based on the probable use of AFFF, this site is also a plausible candidate source of concern.

B. Industrial Facilities

Industrial sources of PFAS include primary manufacturing facilities that produce PFAS or FP and secondary manufacturing facilities that use PFAS or FP in the production processes. As previously stated, there are no known current primary manufacturing facilities in South Carolina. There are, however, secondary manufacturing facilities in South Carolina.

USEPA's PFAS Action Plan presents four (4) industrial sectors as potential PFAS sources of interest (USEPA 2019a):

- Organic Chemicals, Plastics and Synthetic Fibers (OCPSF)
- Pulp and Paper
- Textiles
- Airports (see Section A immediately above)

ITRC also lists leather, rubber, metal plating and etching, wire manufacturing, industrial surfactants, resins, molds, photolithography and semiconductors as potential sources of PFAS (ITRC 2017). In order to distinguish between industries that may or may not be secondary manufacturing facilities, the standard industrial classification (SIC) code(s) will be used because SIC codes provide a descriptor of the types of activities that occur at a given industry.

The BOW used two (2) criteria to assess industrial facilities in South Carolina who may use PFAS or FP in their production processes, both of which must be met to be considered a more likely industrial PFAS source in this Strategy:

- process wastewater from the industry is discharged into a surface water through a National Pollutant Discharge Elimination System (NPDES) permit, onto the land through a No Discharge (ND) permit, or to a municipal WWTP through a pretreatment permit; and
- the industry falls under a pertinent SIC code as described by USEPA or that the BOW believes indicates that PFAS or FP could be utilized in the production process(es).

Using the aforementioned criteria, there are 384 industries where PFAS or FP may be or have been used in production (Table 6).

Table 6. Currently-Permitted Potential PFAS Source industries by SIC Code

SIC Descriptor	Total by SIC Descriptor	Total
Organic Chemicals, Plastics and Synthetic Fibers	65	384
Pulp and Paper	11	
Textiles	68	
Airport and Other	240	

C. Landfills

The widespread use PFAS in many consumer, construction and industrial products results in the end-of-life cycle (*i.e.,* disposal) fate to be a landfill. Cell leachate, if not properly contained, handled and disposed, may serve as a contaminant source to the surrounding environment, including nearby drinking water supplies.

Data from the Department's Bureau of Land and Waste Management (BLWM) reports that there are 79 Class 2 landfills and 28 Class 3 landfills currently permitted to accept waste in South Carolina (Table 7). Class 2 landfills

only accept construction and demolition (C&D) debris while Class 3 landfills can accept municipal solid waste (MSW), C&D debris and industrial solid waste. There are also many inactive landfills that operated after 1940 but no longer accept waste.

Table 7. Active/Inactive Permitted Landfills by Type

Status	Classification	Total by Classification	Total by Status	Total
Active	Class 2	79	107	677
	Class 3	28		
Inactive[A]	Class 2[B]	133	570	
	Class 3[B]	228		
	Industrial[C]	208		
	RCRA[D] Subtitle C	1		

A. closed landfills with inactive permits and landfills that no longer accept waste but may still have an active permit
B. inactive landfills may not have been specifically classified as Class 2 or Class 3, but this summary associates those inactive landfills with the most appropriate current classification based on the types of waste they accepted
C. legacy landfills may have been permitted for industrial waste only
D. Resource Conservation and Recovery Act; Subtitle C – hazardous waste landfills; the lone instance in the State is the now-closed and in post-closure care Subtitle C landfill in Pinewood, SC

D. Wastewater Treatment Plants

Domestic/municipal WWTP may accept wastewater from residential and industrial sources, both of which may contain PFAS. The Department classifies privately-owned WWTP as *Domestic* and publicly-owned WWTP as *Municipal.* A WWTP discharge may be covered under an individual or general discharge permit. An individual discharge permit contains site-specific permit conditions whereas a general discharge permit may contain generalized permit conditions for a group of WWTP that share commonalities. The amount of PFAS in WWTP effluent and sludge will be highly dependent upon the percentage of residential vs. industrial inputs and the specific activities at those sources. Municipal WWTP meeting certain criteria may also have a pretreatment program that helps manage the collective inputs of industrial waste into the WWTP.

There are 362 currently-permitted domestic/municipal WWTP in South Carolina. This number does not include those WWTP covered under the *Domestic Wastewater Treatment Plant Dischargers* general NPDES permit because coverage under this permit is for smaller WWTP that meet certain criteria. WWTP covered by this general permit could be sources of PFAS, but their impact on the surrounding environment is likely small relative to domestic/municipal WWTP with individual permit coverages.

A summary of current domestic/municipal WWTPs with individual permit coverages is presented in Table 8 by type and, in the case of municipal WWTP, the presence or absence of a pretreatment program. Industrial WWTP of interest were accounted for in Part III.B above.

Table 8. Currently-Permitted Domestic/Municipal WWTP by Type

WWTP Type	Total by Type	Total
Domestic	146	362
Municipal with Pretreatment Program	90	
Municipal without Pretreatment Program	126	

E. Land Application of Wastewater and Sludge

Domestic/municipal and industrial WWTPs typically form solid by-products, commonly referred to as *sludge*, from their treatment processes. This sludge may contain substances that were once suspended or dissolved in the water column, such as PFAS. Sludge is often sent to a landfill for disposal, but it may also be permitted to be applied to land across South Carolina at approved application rates if both the sludge and land application site meet certain requirements. WWTP effluent may also be applied to land across South Carolina at approved application rates if both the effluent and land application site meet certain requirements. Up to this point, PFAS have not be regulated and, therefore, not evaluated in the decisions to permit land application of effluent or sludge. These sites could contain PFAS if there were PFAS inputs to a WWTP that partitioned into the sludge or passed through the WWTP and exited through the effluent.

The number of land application sites and the amount of effluent or sludge applied to individual sites is difficult to compile as the specific land application rates and sites can change across permit cycles. The BOW is more easily able to quantify the sources of land-applied effluent or sludge, which is summarized in Table 9. By considering WWTP that may have received higher levels of PFAS inputs, individual land application sites that received effluent or sludge from those WWTP can be prioritized. The BOW believes this methodology is the most efficient way to develop the vulnerability risk of drinking water supplies to this potential contaminant source.

Table 9. Active WWTP Currently-Permitted to Land-Apply Effluent and Sludge

WWTP Type	Waste Type	Total by Waste Type
Domestic	Effluent	63
	Sludge	10
Municipal	Effluent	49
	Sludge	60
Industrial	Effluent	137
	Sludge	23

IV. FACTORS INFLUENCING THE VULNERABILITY OF DRINKING WATER TO PFAS

A. PFAS Sources

The potential for any given PFAS source to impact a nearby drinking water source is dependent upon many variables, such as source type, specific activity at the site, duration of the activity, proximity to a drinking water receptor and hydrologic setting (*e.g.,* local groundwater mobility characteristics), among others. A recent study from Brown University reviewed and summarized pertinent peer-reviewed articles on measured groundwater PFAS contamination to help guide future research and management strategies (Guelfo *et al.* 2018).

One objective of the Brown University study was a prioritization of those PFAS sources that represent the highest risk of occurrence in finished drinking water. The authors compiled the measured ranges of PFAS concentrations in groundwater at various sites as documented in peer-reviewed articles throughout the world (by order of magnitude). PFAS contamination at the most probable PFAS source types ranged from highly variable [eight (8) orders of magnitude at DOD facilities] to relatively consistent [(2) orders of magnitude near septic systems]. This speaks to the relative uncertainty of predicting PFAS concentration in groundwater based solely on the general activity at or near a given location.

The ranges of PFAS concentrations found in the groundwater at various sources, as adopted from the Brown University study, are presented in Table 10. Of note are the upper magnitude of these ranges, which depict the highest PFAS contamination found at a given source type during their literature review. The source types in Table 9 are arranged in order from higher maximum PFAS contamination to lower maximum PFAS contamination.

Table 10. Variability of PFAS Concentrations by Source Type

Source Type	Magnitude of PFAS (ppt)[A]	PFAS Source Type
DOD Facilities	10^0-10^7	AFFF Use
PFAS or FP Manufacturing	10^1-10^6	PFAS or FP Manufacturing
Landfills[B]	10^0-10^6	Waste Stream(s)
Airports	10^0-10^5	AFFF Use
Fire Training Areas[C]	10^0-10^5	AFFF Use
Petroleum Refineries	10^0-10^4	AFFF Use
Industrial Sites[D]	10^0-10^4	PFAS or FPs Used in Production Processes
Municipal Sludge[E]	10^1-10^3	Waste Stream (sludge)
Septic Systems	10^0-10^1	Waste Stream

- adapted from Guelfo *et al.* 2018

A. groundwater concentrations at contaminated sites; ppt = parts per trillion
B. review found 10^6 ppt at landfills that accepted waste from a PFAS manufacturer. Other landfills had max of 10^3 ppt
C. represents fire training areas at municipal or private fire training institutions
D. reviewed industrial sites included textiles, furniture, paper and rubber/plastics
E. wastewater inputs to the reviewed municipal WWTP included industries that produce or use PFAS or FP

Another potential PFAS source, WWTP effluent, was not evaluated in the Brown University review (this review only included data from actual groundwater contamination). The BOW reviewed previous studies that measured effluent data from a total of 33 domestic/municipal WWTP and 13 industrial WWTP for the presence of certain

PFAS (3M 2001; Bossi *et al.* 2008, Clara *et al.* 2008). It was unclear as to how many of the domestic/municipal WWTP in these three (3) studies received any amount of wastewater from an industry producing or using PFAS or FP, but at least one (1) WWTP received wastewater from a PFAS or FP manufacturer. None of the 13 the industrial facilities in these studies manufactured PFAS or FP, but all were believed to use PFAS or FP in their production processes.

The combined data from these three (3) studies indicated that effluent from the 33 domestic/municipal WWTPs ranged from 10^1-10^3 ppt of a given PFAS and effluent from the 13 industrial WWTPs ranged from 10^0-10^3 ppt of a given PFAS. At these concentrations, WWTP effluent would likely only be a concern in effluent-dominated streams, which are streams whose flow consists mostly, or entirely, of WWTP effluent, or at sites where WWTP effluent is land-applied.

A brief literature search on groundwater contamination following the land application of industrial sludge failed to reveal any published studies. Lindstrom *et al.* (2011) found PFAS contamination of groundwater by municipal sludge cited in the Brown University study to be on the order of 10^1-10^3 ppt. This is comparable to what the previously noted studies found for PFAS concentrations in domestic/municipal WWTP effluent. Based on the similarities in PFAS concentrations at sites with contaminated groundwater from municipal sludge and in domestic/municipal WWTP effluent and in the absence of site-specific information, it is appropriate to make a similar comparison between industrial WWTP effluent and the potential for land applied industrial sludge to contaminate groundwater.

B. Drinking Water Sources

If a drinking water source contains PFOA and PFOS at concentrations greater than the USEPA HA, actions may need to be taken to ensure the protection of public health. Typical water treatment processes (*i.e.*, conventional treatment) are ineffective at the removal of PFOA and PFOS from source waters (USEPA 2019b). More advanced treatment, such as granular activated carbon (GAC), membrane separation or ion exchange is required to remove PFOA and PFOS from drinking water. Few water treatment plants (WTP) in the State are presently equipped at the scale that would be needed for effective treatment.

Surface Water Sources

Surface waters that typically have abundant flows throughout the year are used for supply by some WTP. There are currently 70 surface water intakes that supply the 61 surface WTP in South Carolina. Many, if not all, of the surface waters that contain an intake could be described as non-effluent dominated; meaning only a small portion of the water within them comes from direct effluent discharge from domestic/municipal or industrial WWTP. Water within these surface sources also typically comes from large watersheds. The influence of a given direct discharge or contaminated groundwater plume would likely be small relative to the amount of assumed PFAS-free (or lower concentrated) water throughout the watershed feeding the surface water.

There are a few scenarios where PFAS could impact a surface water intake. The first would be an intake in an effluent-dominated stream, downstream from a domestic/municipal or industrial WWTP discharge with PFAS-containing effluent. The Department has source water protection areas upstream of each surface water intake. In these areas, a more conservative approach is taken towards the development of WWTP effluent limits. With limited information on PFAS inputs to WWTP and guidance on in-stream regulatory criteria, WWTP effluent limits for PFAS have not been considered up to this point. Another scenario of concern would be an intake in a stream with a relatively low flow that contains a significant PFAS-containing groundwater plume feeding the surface water directly upstream of the intake. A third scenario is the inflow of surface waters from a neighboring state that may be impacted by PFAS in that state.

Groundwater Sources

In an overall sense, groundwater wells are used to supply drinking water to two (2) different types of systems in the State: public wells serving more than one (1) residence and private wells serving a single residence. There are approximately 585 active public wells and hundreds of thousands of private wells in South Carolina. A contaminated groundwater plume is typically slow moving (on the order of 10^0-10^1 feet per year) and the effect on a groundwater well can be long and concentrated.

In certain parts of South Carolina, private wells may be more vulnerable to surface and shallow sub-surface inputs than the public wells. The typical depths of each well type are dependent upon their location. For example, private and public wells in the Piedmont region of South Carolina tend to be drilled at roughly the same depths; whereas private wells in the Lower Coastal Plain and Upper Coastal Plain are often drilled shallower than public wells. Therefore, private wells tend to be more vulnerable to surface and shallow sub-surface inputs than public wells in the Lower Coastal Plain and Upper Coastal Plain.

The Department seeks to prevent public wells from becoming contaminated by identifying areas of concern regarding pollution sources through a wellhead protection area (WHPA) delineation. The WHPA delineation requires a 100-ft *pollution-free* radius around a well and only considers currently known real and potential pollution sources; WHPA does not protect against new pollution sources that arise following the evaluation. WHPA delineations are also limited to public wells; the same scrutiny is not put on new private wells. Collective efforts from a myriad of the Department's regulatory programs also use source water protection of aquifers to protect all drinking water wells.

C. Aquifers

South Carolina can generally be divided into three (3) regions, each with differing vulnerability to surface and shallow sub-surface inputs: Piedmont, Upper Coastal Plain and Lower Coastal Plain. The most vulnerable aquifers tend to be in:

- the Upper Coastal Plain, which is characterized by relatively thin, unconsolidated sand aquifers overlain by sandy soils. Private and public wells, by necessity, are relatively shallow here.
- the Piedmont region above the Fall Line, which consists of fractures in igneous and metamorphic crystalline rock and is moderately vulnerable to surface inputs due to the relatively shallow occurrence of the fractures.

Aquifers of the Lower Coastal Plain tend to be the least vulnerable due to their greater depth below the surface and better confinement below beds of low permeability. Most public wells in this region are deeper than 300 feet and can reach depths of over 2,000 feet. Private wells in this region are usually much shallower than public wells and are often above the protective confining layer.

Although generalizations can be made about the varying regions, the actual vulnerability of a given aquifer or drinking water source is extremely variable. Sub-surface geology and hydrology can be wildly heterogeneous and unpredictable over relatively short distances. The creation of a hardline map to delineate these regions would be impractical and, ultimately, imprecise. The BOW uses a general understanding of these regions to make broad assumptions about the vulnerability of a given aquifer. If available, data on the soils and depths of actual drinking water wells in an area can help deduce the vulnerability of a drinking water source to influence from the surface and shallow sub-surface.

V. STRATEGY TO ASSESS DRINKING WATER VULNERABILITY TO PFAS

A. Source Impact and Drinking Water Vulnerability Index

Numerous factors determine the potential impact of a given PFAS source on the vulnerability of a given drinking water system to PFAS. The BOW believes the three (3) most significant pragmatic factors in vulnerability are:

- PFAS source type
- drinking water source type
- groundwater aquifer system type

As discussed herein, statewide review of these factors revealed a variety of potential PFAS sources; hundreds of thousands of individual drinking water (*i.e.,* private well) sources; and, three (3) major groundwater aquifer systems along with surface water systems. The permutations and combinations of these large factors yields a vast number of possible and plausible public exposure pathways. To better direct the use of limited resources, each PFAS source type, drinking water source type and groundwater aquifer type were ranked by their potential influence on drinking water vulnerability to PFAS, as discussed below.

PFAS Source Type

Current and past research has shown that PFAS source type (*i.e.,* activity at a given site) is a large factor in the probability of PFAS exposure from that source. Information from Part IV.A was used to rank the more likely source types. The rankings in Table 11 generally follow the upper magnitude of PFAS groundwater contamination described by Guelfo *et al.* (2018). Septic tanks are absent from the rankings based on their relatively low potential for PFAS exposure in the literature.

Table 11. Ranking of PFAS Source Type on Drinking Water Vulnerability

Source Type	Impact Rank	Approximate Number of Known Sites
DOD/DOE Facilities	1	12
PFAS or FP Manufacturing[A]	2	0
Landfills	3	677
Part 139 Airports	4	8
Fire Training Areas[B]	5	>2[C]
Petroleum Refineries[A]	6	0
Industrial Sites[D]	7	384
WWTP[E]	8	746

A. no known facilities in South Carolina

B. represents fire training areas at municipal or private fire training institutions

C. presently, there are two (2) known past/present fire training areas in South Carolina

D. industries that use or are believed to use PFAS or FP in their production processes and have either a direct discharge of their wastewater (NPDES/ND permit) to surface waters or send wastewater to a municipal WWTP that has a pretreatment program

E. domestic/municipal and industrial WWTP that produce treated effluent and sludge. Industrial WWTP here are limited to those WWTP at industries that use or are tentatively indicated to use PFAS or FP in their production processes

Note: land application sites will be identified through their Industrial or WWTP sources

Groundwater contamination at land application sites reviewed by Lindstorm *et al.* (2011) was limited to sludge from municipal WWTP. No literature was found to suggest that a land application site receiving municipal sludge was a higher risk than one receiving industrial sludge, industrial effluent or domestic/municipal effluent. Similarly, the available literature on PFAS in WWTP effluent did not suggest a significant difference between domestic/municipal effluent and industrial effluent. The *WWTP* source type in Table 10 combines domestic/municipal or industrial WWTPs of interest, regardless of disposal method, into one (1) broad source type since there is no information from the literature to rank one (1) of these unique scenarios over another. If a given WWTP is indicated to be a likely source of PFAS, then the areas that may be impacted by effluent and sludge (*i.e.,* surface waters, land application areas) will be elevated in the vulnerability conclusion for evaluation of drinking water if users (*i.e.,* receptors) are present.

The groundwater contamination data in the literature was highly variable within each source type. The upper magnitudes within a given source type were often driven by a worst-case scenario (*e.g.,* waste from a PFAS manufacturer). However, in the absence of site-specific information, this approach is adopted as the more logical and defensible way to rank source types given the present state of the scientific knowledge on this issue.

Drinking Water Source Type

The characteristics of a given drinking water source will also influence the potential for PFAS exposure. Based on the general characteristics outlined in Part IV.B for each type of drinking water source, it may be assumed that a groundwater well near a PFAS source would be higher risk than a surface water intake which generally receives inputs from large watersheds. As such, groundwater well vulnerability is ranked higher than surface water intakes in Table 12.

There are similarities between private and public wells. In some aquifers, these can be at similar depths and their vulnerability to surface contamination may be comparable. However, private wells in other aquifers tend to be much shallower than public wells. Therefore, private wells are ranked as the more vulnerable drinking water source type than public system wells.

Table 12. Ranking of Drinking Water Source Type on Drinking Water Vulnerability

Drinking Water Source Type	Impact Rank	Approximate Population[A]
Private Wells	1	1,000,000
Public Wells	2	1,000,000
Surface Water Intakes	3	3,000,000

A. estimate of population to show approximate portion of population served by each drinking water source type

Groundwater Aquifer Type

Based on the aquifer characteristics described in Part IV.C, it is reasonably and defensibly assumed that the wells in the Upper Coastal Plain and Piedmont are more vulnerable to surface and shallow sub-surface contamination than those in the Lower Coastal Plain (Table 13). If PFAS are present at the surface or shallow sub-surface, the potential for PFAS to migrate into an aquifer is highly dependent upon localized geology and hydrology. However, in the absence of localized geologic and hydrologic information, but based on the general and area-related knowledge of the lithology and stratigraphy for the main aquifer units, this ranking is the most logical and defensible way to rank aquifer vulnerability.

Table 13. Ranking of Groundwater Aquifer Areal Zone on Drinking Water Vulnerability

Aquifer	Impact Rank
Upper Coastal Plain	1
Piedmont	2
Lower Coastal Plain	3

B. Assessment Design

An investigation of individual potential PFAS sources as the sole trigger for drinking water assessment will be resource-intensive and will require a significant period of duration for execution. For present public health purposes, it is more pressing to determine if PFAS are present in a drinking water source than assignment of the source(s) of PFAS, if found in drinking water. Based on the Strategy described herein, different approaches will be adopted for public systems and private wells to meet the following goals:

- to be fit-for-purpose;
- to be resource-efficient (time and money); and,
- to provide actionable and extendable data on a timely basis for public health decision-making.

Private Wells

Based on the foregoing discussion, the BOW believes the more important questions for determining the vulnerability of a drinking water source, but especially for private wells, to PFAS are:

- *How difficult is it for surface and/or shallow sub-surface inputs to reach a drinking water source?*
- *Is there a likely source of PFAS near a drinking water source?*

Consequently, development of answers to these two (2) questions will drive the BOW's assessment design to prioritize PFAS sampling for private wells in the State.

The existence of hundreds of thousands of private wells across the State make it infeasible to sample and analyze each well. Accordingly, the BOW plans to implement the Strategy discussed herein on a technical evaluation basis to prioritize identifying the more (apparent) at-risk private wells. The identified wells will then be sampled and analyzed, pending receipt of owner permission. The Strategy will be implemented by:

- the more vulnerable aquifers (upper Coastal Plain and Piedmont) will be the initial focus
- potential PFAS sources over that aquifer and private wells near those sources will be located. PFAS sources will be evaluated in the rank order from Table 10 unless other information becomes available that would merit a modification to the Strategy.
- For example, private wells near DOD sites in the Upper Coastal Plain would be evaluated first.
    - Identified at-risk wells will then be sampled and analyzed for PFAS.
    - Next, private wells near Class 2 and Class 3 landfills in that aquifer, and so-on until each potential source type within the aquifer has been addressed.
    - The process would then be repeated for the Piedmont and then for the Lower Coastal Plain.

Public Systems

Consequently, in order to meet the goals of resources efficiency as to extend the application of the data acquired as far as defensible for public health decision-making, the BOW plans to:

- sample and analyze the finished water at the filter/treatment plants for the 583 community water systems (CWS), but prior to final technology treatment such as GAC or reverse osmosis, for the presence of PFAS.

- A CWS is a system that has more than 15 taps or serves more than 25 year-round residents.

This strategy-based element of the assessment design affords the BOW the ability to evaluate the status of PFAS exposure in drinking water for approximately 80% of the State's population per Table 11.

The BOW is aware that other groups are performing site investigations for PFAS contamination (*e.g.,* DOD) and that some community water systems are performing PFAS analyses on their own initiative. Accordingly, the BOW notes that it will be crucial to collaborate appropriately with these groups to ensure that collective efforts are not duplicated.

VI. PATH FORWARD

A. Current Known Issues and Previously-Identified Vulnerable Drinking Water Systems

The BLWM has been working closely with the DOD on their military base investigations. DOD policy is to investigate PFAS as an emerging contaminant under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). BLWM is included in the DOD process as a stakeholder to review DOD activities and findings. If PFAS is found in groundwater at DOD facilities, the DOD performs follow-up assessments to ascertain if nearby drinking water user (*i.e.,* receptors) have been impacted. To date, no complete pathways for ingestion of PFAS-affected drinking water have been identified (Table 14).

Table 14. PFAS Impacts on Drinking Water at South Carolina DOD Facilities

Facility	City	Known Impact to Off-Base Wells[A]	Known Impact to On-Base Wells[A]
Charleston Naval Complex	Charleston	None	None; No Wells – Public Supply
Fort Jackson	Columbia	None	None; No Wells - Public Supply
Joint Base Charleston - Air	Charleston	None	None; No Wells - Public Supply
Joint Base Charleston - Weapons	Charleston	None	None; No Wells - Public Supply
Marine Corps Air Station	Beaufort	None	None; No Wells - Public Supply
Marine Corps Recruit Depot	Port Royal	None	None; No Wells -- Public Supply
McEntire Joint National Guard Base	Eastover	None	None; No Wells -- Public Supply
Myrtle Beach Air Force Base	Myrtle Beach	None	None; No Wells -- Public Supply
North Auxiliary Airfield	Orangeburg	None	None; No Wells -- Public Supply
Poinsett Electronic Combat Range	Wedgefield	None	None; No Wells - Public Supply
Shaw Air Force Base	Sumter	Assessment Planned by DOD	None[B]

A. per DOD reporting to BLWM as of January 27, 2020.
B. five (5) wells present; all have been sampled three (3) times over the past year with all reporting non-detects.

Five (5) private wells proximate to the Able Contracting response action project in Jasper County were sampled and analyzed in September 2019 for PFAS by USEPA Method 537.1 due to the nature of the material (*i.e.,* construction and demolition debris) on the project site. All wells returned non-detects for all 18 analytes in the suite with no elevated detection or reporting limits.

The USEPA (lead agency) and BLWM are currently continuing to assess some land application sites in the Pee Dee Region of the State where there has been some PFAS impact on private well water.

B. Implementation Schedule

The BOW's Strategy for the evaluation of PFAS in drinking water will be implemented along the flow of the following schedule:

First Quarter (January-March) 2020

- prepare and award procurement for external laboratory analyses
- produce geographic information system exhibits that show the locations of potential PFAS sources and their proximity to known drinking water sources
- prepare and obtain approval of Quality Assurance Project Plan
- ascertain and acquire PFAS data from CWS that have performed those analyses
- develop schedule for CWS sampling and coordinate activities with CWS
- commence CWS sampling and analyses
- evaluate sample results against the USEPA HA for PFOA and PFOS
- evaluate sample results for other PFAS analytes in the suite
- notify CWS of sample results and provide technical support, as necessary
- update Department web page with received data

Second Quarter (April-June) 2020

- continue CWS sampling and analyses
- evaluate sample results against the USEPA HA for PFOA and PFOS
- evaluate sample results for other PFAS analytes in the suite
- notify CWS of sample results and provide technical support, as necessary
- update Department web page with received data
- identify initial round of private wells to be sampled

Third Quarter (July - September) 2020

- continue CWS sampling and analyses
- obtain permission, then collect and analyze samples in initial round of private wells
- evaluate sample results against the USEPA HA for PFOA and PFOS
- evaluate sample results for other PFAS analytes in the suite
- notify CWS of sample results and provide technical support, as necessary
- notify private well owners of sample results and provide technical support, as necessary
- update Department web page with received data

Fourth Quarter (October - December) 2020

- continue CWS sampling and analyses
- obtain permission, then collect and analyze samples in initial round of private wells
- evaluate sample results against the USEPA HA for PFOA and PFOS
- evaluate sample results for other PFAS analytes in the suite
- notify CWS of sample results and provide technical support, as necessary
- notify private well owners of sample results and provide technical support, as necessary
- update Department web page with received data

First Quarter (January - March) 2021

- assess effectiveness of Strategy; determine if adjustments to the Strategy and resource utilization should be made
- prepare and issue a summary report for 2020 describing work performed and results obtained with discussion of consequential public health outcomes

C. Other Considerations and Outcomes

In this Strategy the BOW is most concerned with protecting public health. Accordingly, resources will be focused on the analysis of drinking water being provided as opposed to discovering exact PFAS-source locations. If it is determined that a drinking water supply has been impacted by PFAS, then at that time, a source investigation will be designed and implemented.

Although only PFOA and PFOS are addressed by the USEPA HA, the data provided on other PFAS from USEPA Methods 533 and 537.1 will have value in that they will provide a broader evaluation of the presence of absence of PFAS in water supplies, irrespective of the USEPA HA.

The wide ranges of PFAS contamination at different source types not only highlights heterogeneity between source types, but also those sites used for similar activities. For instance, there is no rule that all DOD sites are a higher risk than all landfills. Without case-specific information about PFAS use or disposal at a given site, the BOW believes this Strategy is the more efficient way to discover drinking water contaminated by PFAS. If information becomes available for a specific water source that would heighten the apparent risk associated with PFAS in that source, such sources will be prioritized over sites with limited or no information.

D. Adaptability

The BOW reserves the right to alter this Strategy as new or updated information is presented. The assessment of the Strategy's effectiveness at the end of the PWS sampling phase (first and second quarters in 2020 will help guide future efforts in the private well phases later in 2020 and there on). The Strategy is expected to continue as described in Section V.B, unless new information becomes known that would alter the Strategy. Similarly, an evaluation of resource use and availability will direct future implementation of the Strategy.

E. Communications Plan

The BOW commits that the results of this Strategy will be communicated in a timely, consistent and transparent fashion. Throughout the implementation of this Strategy, the BOW will communicate with water systems and the public in the following manner:

- a BOW PFAS Strategy webpage will be developed and maintained current on the BOW website, which will contain pertinent documents and data.
- the BOW will notify each PWS and/or private well owner of sample results within seven (7) days of receiving the final data from the laboratory.
- the BOW will post PWS sample results to the BOW PFAS Strategy webpage within 15 days of receiving the final data analysis from the laboratory.
- sample results from private wells will be summarized by county (i.e., individual well owner identification will remain confidential) on the BOW PFAS Strategy webpage within 15 days of receiving the final data analysis from the laboratory.

The general messaging spines for the resulting data from the non-regulatory, voluntary sampling will be:

- Concentrations of PFOA and PFOS exceed 70 ppt, either individually of combined:
  - CWS – the Department will expect the CWS to notify their customers of the findings and will encourage the CWS to develop a plan to address mitigation of PFAS analytes in the system's finished water.
  - Private well – the Department will advise that an alternate water source be used for consumption (*e.g.,* drinking, cooking, brushing teeth, preparing infant formula).

- Concentrations of PFOA and PFOS do not exceed 70 ppt, either combined or individually:
  - CWS – the Department will expect the CWS to notify their customers of the findings and to inform the Department of how the CWS has chosen to handle this scenario regarding their finished water.
  - Private well -- the Department will advise the user to become informed on the presence of PFAS in their water in order to make a personal decision of continued consumption of the water.

- Concentrations of PFOA and PFOS are non-detect, but other PFAS analytes are detected:
  - CWS – the Department will encourage the CWS to notify their customers of the findings.
  - Private well -- the Department will advise the user to become informed on the presence of PFAS in their water in order to make a personal decision of continued consumption of the water.

- No PFAS analytes are detected:
  - CWS and Private well – the Department will advise that there does not appear to be an unacceptable risk to the user of the water, within the context of the PFAS parameter coverage and time of the testing.

Based on the present regulatory status of PFAS (*i.e.,* non-regulated), the Department's role at this time is to make community water systems management and private well owners aware of data obtained from their water supplies and to advise about available information that can be used to make decisions for addressing a situation revealed by the acquired data. Under this present regulatory status, the choices for addressing PFAS-related issues in drinking water remain with the community water systems and private well owner.

VII. REFERENCES CITED

3M Company Environmental Laboratory. 2001. Environmental Monitoring – Multi-City Study Water, Sludge, Sediment, POTW Effluent and Landfill Leachate Samples. 3M. St. Paul, MN.

AECOM. 2019. 2018 PFAS Sampling of Drinking Water Supplies in Michigan. AECOM. Grand Rapids, MI.

Agency for Toxic Substances and Disease Registry. 2017. Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) Frequently Asked Questions. Fact Sheet. Agency for Toxic Substances and Disease Registry. Atlanta, GA. Updated August 22, 2017.

Anderson, P.D., N.D Denslow, J.E. Drewes, A. W. Olivieri. D. Schlenk, G.I. Scott and S.A. Snyder. 2012. Monitoring Strategies for Chemicals of Emerging Concern (CECs) in California's Aquatic Ecosystems. Recommendations of a Scientific Advisory Panel. Technical report 692 by the Southern California Coastal water Research Project, Costa mesa, CA to the California Water Resources Control Board. 215pp.

Arhens, L. and M. Bundschuh. 2014. Fate and Effects of Poly- and Perfluoroalkyl Substances in the Aquatic Environment: A Review. Environmental Toxicology and Chemistry, 33 (9): 1921-1929.

Bossi, R., J. Strand, O. Sortkjær and M.M. Larsen. 2008. Perfluoroalkyl Compounds in Danish Wastewater Treatment Plants and Aquatic Environments. Environment International, 34 (4): 443-450.

Brusseau, M.L. 2018. Assessing the Potential Contributions of Additional Retention Processes to PFAS Retardation in the Subsurface. Science of the Total Environment, 613: 176-185.

Centers for Disease Control and Prevention. 2019. Fourth National Report on Human Exposure to Environmental Chemicals, Updated Tables, January 2019, Volume One. Atlanta, GA.

Clara, M., C. Scheffknecht, S. Scharf, S. Weiss and O. Gans. 2008. Emissions of Perfluorinated Alkylated Substances (PFAS) from Point Sources – Identification of Relevant Branches. Water Science and Technology, 58 (1): 59-66.

Ding, G. and W.J.G.M. Peijnenburg. 2013. Physicochemical Properties and Aquatic Toxicity of Poly- and Perfluorinated Compounds. Critical Reviews in Environmental Science and Technology, 43 (6): 598-678.

Giesy, J.P., J.E. Naile, J.S. Khim, P.D. Jones and J.L. Newsted. 2010. Aquatic Toxicology of Perfluorinated Chemicals. Reviews of Environmental Contamination and Toxicology, 202: 1-52.

Guelfo, J.L. and C.P. Higgins. 2013. Subsurface Transport Potential of Perfluoroalkyl Acids at Aqueous Film-Forming Foam (AFFF)-impacted Sites. Environmental Science and Technology, 50 (19): 10554-10561.

Guelfo, J.L., T. Marlow, D.M. Klein, D.A. Savitz, S. Frickel, M. Crimi and E.M. Suuberg. 2018. Evaluation and Management Strategies for Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water Aquifers: Perspectives from Impacted U.S. Northeast Communities. Environmental Health Perspectives, 126 (6): 065001.

International Technology and Regulatory Council. 2019. Regulations, Guidance, and Advisories for Per- and Polyfluoroalkyl Substances (PFAS), Section 4 Tables. Interstate Technology Regulatory Council. Washington, DC. Updated June 30, 2019.

International Technology and Regulatory Council. 2018a. Aqueous Film-Forming Foam (AFFF). Fact Sheet. Interstate Technology Regulatory Council. Washington, DC.

International Technology and Regulatory Council. 2018b. Environmental Fate and Transport for Per- and Polyfluoroalkyl Substances. Fact Sheet. Interstate Technology Regulatory Council. Washington, DC.

International Technology and Regulatory Council. 2017. History and Use of Per- and Polyfluoroalkyl Substances (PFAS). Fact Sheet. Interstate Technology Regulatory Council. Washington, DC.

Krafft, M.P. and J.G. Riess. 2015. Selected Physicochemical Aspects of Poly- and Perfluoroalkylated Substances Relevant to Performance, Environment and Sustainability – Part One. Chemosphere, 129: 4-19.

Lee, J.L. and I.R. Schultz. 2010. Sex Differences in the Uptake and Disposition of Perfluorooctanoic Acid in Fathead Minnows after Oral Dosing. Environmental Science and Technology, 44 (1): 491-496.

Lindstrom, A.B., M.J. Strynar, A.D. Delinsky, S.F. Nakayama, L. McMillan, E.L. Libelo, M. Neill and L. Thomas. 2011. Application of WWTP Biosolids and Resulting Perfluorinated Compound Contamination of Surface and Well Water in Decatur, Alabama, USA. Environmental Science and Technology, 45 (19): 8015-8021.

MacDonald, M.M., A.L. Warne, N.L. Stock, S.A. Mabury, K.R. Solomon and P.K. Sibley., 2004. Toxicity of Perfluorooctane Sulfonic and Perfluorooctanoic Acid to *Chironomus tentans*. Environmental Toxicology and Chemistry, 23 (9): 2116-2123.

Maruya, K.A., D. Schlenk, P.D. Anderson, N.D. Denslow, J.E. Drewes, A.W. Olivieri, G.I. Scott and S.A. Snyder. 2014. An Adaptive, Comprehensive Monitoring Strategy for Chemicals of Emerging Concern (CECs) in California's Ecosystems. Integr. Environ. Assess. Manag. 10(1): 69-77.

National Toxicology Program. 2016. Monograph on Immunotoxicity Associated with Exposure to Perfluorooctanoic Acid (PFOA) or Perfluorooctane Sulfonate (PFOS). Office of Health Assessment and Translation, National Toxicology Program. National Institute of Environmental Health Services. Durham, NC.

South Carolina Fire Academy. 2019. Facilities and Props. South Carolina Fire Academy Website. http://www.scfa.state.sc.us/InsideSCFA/index.asp?file=facility.htm. Accessed August 1, 2019.

South Carolina State Firefighters' Association. 2019. 2019 Department Directory. South Carolina State Firefighters' Association. Columbia, SC.

Sepulvado, J.G., A.C. Blaine, L.S. Hundal and C.P. Higgins. 2011. Occurrence and Fate of Perfluorochemicals in Soil Following the Land Application of Municipal Biosolids. Environmental Science and Technology, 45 (19): 8106-8112.

Sharpe, R.L., J.P. Benskin, A.H, Laarman, S.L. MacLeod, J.W. Martin, C.S. Wong and G.G. Goss. 2010. Perfluorooctane Sulfonate Toxicity, Isomer-Specific Accumulation, and Maternal Transfer in Zebrafish (*Danio rerio*) and Rainbow Trout (*Oncorhynchus mykiss*). Environmental Toxicology and Chemistry, 29 (9): 1957-1966.

United States Department of Defense. 2017. Aqueous Film Forming Foam. Report to Congress. Department of Defense. Washington, DC.

United States Environmental Protection Agency. 2000. EPA and 3M Announce Phase Out of PFOS. Press Release. US Environmental Protection Agency. Released May 16, 2000.

United States Environmental Protection Agency. 2019a. EPA's Per- and Polyfluoroalkyl Substances (PFAS) Action Plan. EPA 823-R-18-004. Office of Water. US Environmental Protection Agency. Washington, DC.

United States Environmental Protection Agency. 2019b. https://iaspub.epa.gov/tdb/pages/general/home.do. Accessed August 6, 2019.

United States Environmental Protection Agency. 2017. The Third Unregulated Contaminant Monitoring Rule (UCMR 3): Data Summary, January 2017. EPA 815-S-17-001. Office of Water. US Environmental Protection Agency. Washington, DC.

Wang, Z., J.C. DeWitt, C.P. Higgins and I.T. Cousins. 2017. A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFAS)? Environmental Science & Technology, 51: 2508-2518.