Strategy to Assess the Impact of Per- and Polyfluoroalkyl Substances on Ambient Surface Waters in South Carolina

Bureau of Water

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SC Department of Natural Resources
SC Manufacturers Alliance
SC Rural Water Association
SC Water Quality Association
US Geological Survey, South Atlantic Water Science Center
Upstate Forever

Table of Contents

Acronyms Used

AFB	United States Air Force base
AFFF	Aqueous film forming foam
ARFF	Aircraft rescue and firefighting
ATSDR	United States Agency for Toxic Substances and Disease Registry
BOW	South Carolina Dept. of Health and Env. Control Bureau of Water
CDC	United States Centers for Disease Control and Prevention
CWS	Community water system
DHEC	South Carolina Department of Health and Environmental Control
DOD	United States Department of Defense
DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
GP	DHEC General Discharge permit
HUC	United States Geological Survey Hydrologic Unit Code
LDL	Low density lipoprotein
MCL	Maximum contaminant level
MDH	Minnesota Department of Health
MPCA	Minnesota Pollution Control Agency
NHANES	National Health and Nutrition Examination Survey
ND	DHEC No Discharge permit
NPDES	National Pollutant Discharge Elimination System
OCPSF	Organic chemicals, plastics and synthetic fibers industrial classification
PFAA	Perfluoroalkyl acids
PFAS	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFDeA	Perfluorodecanoic acid
PFHxS	Perfluorohexane sulphonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
POTW	Publicly owned treatment works
SIC	Standard Industrial Classification
USGS	United States Geological Survey
WWTP	Wastewater treatment plant

Note: List does not include all PFAS and precursor compounds identified in Table 2.

Units of Measure Used

ng/L	nanograms per liter
ppt	parts per trillion

List of Tables

List of Figures

Executive Summary

The purpose of this Surface Water Strategy is to guide the South Carolina Department of Health and Environmental Control (DHEC) in assessing per- and polyfluoroalkyl substances (PFAS) in the State's surface waters. The Strategy has identified a series of 48 priority watersheds distributed across each major river basin within the State based on past and present sources that may have released or may release PFAS to the environment. The watersheds were selected by major river basin to ensure adequate representation throughout the State. The results of this screening level program will be communicated to the public and will inform future DHEC actions related to addressing possible human health and ecological impacts associated with PFAS exposure.

PFAS are a broad class of more than 3,000 man-made organic chemicals. Production of these compounds began in the 1940s. The chemical properties of PFAS give them the unique ability to repel both oil and water and as such have been widely used in commercial products. Commercial uses for PFAS include coatings for nonstick cookware, food packaging, stain-resistant fabrics, water-resistant clothing, and metal plating. PFAS are also used in firefighting foams (aqueous film forming foam, AFFF), cosmetics, and industrial surfactants. PFAS compounds are highly persistent in the environment and resist degradation. Hence, PFAS chemicals are commonly referred to as *forever chemicals*. Among the documented sources of PFAS to the environment, four are considered primary sources: fire training/response sites (military bases, civilian airports), industrial sites, landfills, and wastewater treatment plants.

PFAS have been found in the blood of animals and humans worldwide. The primary non-occupational route of exposure to PFAS is diet, meaning PFAS may also pose ecological risks as they are present in most food webs. The Agency for Toxic Substances and Disease Registry (ATSDR) notes possible associations between specific PFAS and several health outcomes including liver damage, increased total and low-density lipoprotein cholesterol, pregnancy-induced hypertension and preeclampsia, thyroid disease, decreased antibody response to vaccines, increased risk of asthma, decreased fertility, and decreased birthweight.

PFAS are ubiquitous in the environment due to their long-standing use in consumer, commercial, and industrial products and applications. Because the compounds are stable and mobile, they can be present in most environmental media including air, soil and sediment, groundwater, surface water, and biota (plants and animals). However, the distributions and concentrations of PFAS in environmental media are dependent on proximity to a potential source of release, nature of the source, and local geology, hydrology, and water chemistry. As such, a specific sampling plan will be developed for each priority watershed based on the number of potential PFAS sources and types present, source relationships to the river and stream network, size (class) of the waterways, and feasibility and accessibility of target areas. Based on these considerations, specific media (*e.g.*, surface water, finfish, shellfish) for testing will be determined.

The Surface Water Strategy presents a scalable framework from which the State can: 1) evaluate which release sources may be impacting ecological integrity and pose human health concerns; 2) determine which areas of the State may be most impacted by PFAS; and, 3) identify what environmental media may be accumulating PFAS (and what type of PFAS).

Introduction

Background on Per- and Polyfluoroalkyl Substances

Per- and polyfluoroalkyl substances (PFAS) are a broad class of more than 3,000 synthetic fluorinated (carbon-fluorine bonds) organic chemicals. PFAS are man-made and do not occur naturally. Production of these compounds began in the 1940s. The chemical properties of PFAS give them the unique ability to repel both oil and water and as such have been widely used in commercial products. Commercial uses for PFAS include coatings for nonstick cookware, food packaging, stain-resistant fabrics, water-resistant clothing, and metal plating. PFAS are also used in firefighting foams, cosmetics, and industrial surfactants (Wang *et al*. 2017).

Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) were the two most widely used PFAS compounds. Though now phased out of commercial and industrial production, PFOS and PFOA remain the two most widely studied PFAS chemicals. PFOS and other PFAS chemicals were used in the production of aqueous film forming foam (AFFF). AFFF has been widely used to extinguish hydrocarbon fires and are prevalent particularly in the vicinity of military bases, firefighting training facilities, airports, and petroleum refineries. Further, due to the ubiquitous presence of PFAS in everyday commercial products, the waste stream from landfills, industrial facilities, municipal sludge and treated effluent from wastewater treatment plants (WWTPs), and septic systems represent important source pathways for PFAS entry into the environment.

PFOS, PFOA, and other PFAS compounds are highly persistent in the environment and resist degradation. Hence, PFAS chemicals are commonly referred to as *forever chemicals*. However, PFAS chemicals were not documented in wildlife tissues until the early 2000s (Giesy and Kannan 2001) despite widespread use for more than a half century. In recent years, awareness of the presence of these chemicals in the environment, their tendency to bioaccumulate and biomagnify in the food chain, and their potential to impact human health has increased prompting the United States Environmental Protection Agency (EPA) to release drinking water health advisories for PFOS and PFOA in 2016 (81 CFR 33250).

Since then, state and tribal governments have recognized more broadly the importance of PFAS in the environment and to, varying degrees, developed or implemented study plans to assess drinking water and surface water or to adopt drinking water standards such as Maximum Contaminant Levels (MCLs). In January 2020, the South Carolina Department of Health and Environmental Control (DHEC) Bureau of Water (BOW) released the State's study plan (Drinking Water Strategy) to assess PFAS concentrations in all 583 public/community water systems (CWS) as well as in potentially vulnerable private wells located in susceptible aquifers or near potential sources of PFAS to the environment (DHEC 2020).

Environmental Fate and Transport

Sources and Transport

Certain PFAS are no longer manufactured in the United States, including PFOS and PFOA. In 2002, 3M voluntarily phased out production of PFOS. In 2006, the EPA PFOA Stewardship Program invited eight leading PFAS manufacturing companies to reduce PFOA emissions by 95% by 2010 and all emissions by 2015. All companies successfully met the goal of the program (EPA 2016, 2018). There are no current facilities known to produce PFAS in South Carolina; however, PFAS may be, or have been, used in industrial processes or to produce commercial/consumer products in South Carolina.

Among the documented sources of PFAS to the environment, four are considered primary sources: fire training/response sites, industrial sites, landfills, and wastewater treatment facilities/biosolids (ITRC 2018).

The Department of Defense (DOD) bases, Department of Energy (DOE) facilities, civilian airports, and firefighting training facilities used AFFF for decades to extinguish hydrocarbon fires. Multiple AFFF formulations have been produced over the years. The fluorosurfactants in AFFF are produced by electrochemical fluorination or fluorotelomerization processes, both of which contain a diverse mixture of PFAS (Barzen-Hanson *et al.* 2017). AFFF was used at these sites for a variety of reasons and at different rates. The pathways of release of PFAS to the environment from firefighting activities include through atmospheric dispersion and deposition; diffusion, dispersion, advection and transformation of precursors in sediment, surface water, soil, and groundwater; and transformation of precursors in biota (ITRC 2018). Perfluoroalkyl acids (PFAA) are a PFAS subgroup which includes PFOS and PFOA. PFAA precursors are a broad class of polyfluorinated compounds (*e.g.,* alcohols, acids, amides) that when transformed yield a PFAA terminal product.

Industrial sites include both facilities that produce or synthesize PFAS containing products and secondary manufacturing facilities. Secondary manufacturing facilities are those that use PFAS containing compounds in production of commercial goods, such as those identified above, or in industrial processes. The pathways for industrial release of PFAS to the environment are similar to fire/training response sites except that industrial facilities may treat wastewater on-site or send wastewater to a WWTP. The treated wastewater may be land applied or discharged to surface water. Uncontrolled releases of PFAS from industrial sites may also occur.

Landfills and non-permitted disposal sites may harbor PFAS-containing consumer goods, industrial waste, and sludge/biosolids from WWTPs. A composite liner has been a requirement for newly constructed municipal solid waste, construction and demolition, and industrial landfills since the 1990s (40 CFR 258.40). Landfills constructed prior to this did not require a liner and, thus, may present a higher potential for release of PFAS to the environment. The release pathways of PFAS to the environment from disposal facilities are similar to industrial sites as landfill leachate may either be treated on-site or diverted to a WWTP. Uncontrolled releases may also occur.

Municipal and industrial WWTP facilities can release PFAS to the environment as direct point source discharge, through facility malfunctions, as sludge/biosolids waste production, and through atmospheric deposition if the facility incinerates waste. Further, PFAA may be produced from oxidation of precursors during the treatment process. The composition and concentration of PFAS in these various environmental pathways are functions of the WWTP's influent, biological and chemical transformation of substances to intermediate or terminal degradation products, and physical/chemical partitioning. The application of industrial and municipal biosolids as a soil amendment to agricultural fields represents an emerging and potentially important spatially distributed (nonpoint) source of PFAS to groundwater, sediment, soil, surface water, and biota (DHEC 2019).

Partitioning and Transformation

The PFAA group of PFAS is generally the most studied due to their widespread use and documented presence in environmental media. PFAA are commonly divided into two categories: short-chain and long-chain based on the number of carbons present in the chemical. PFOS (sulfonate head) and PFOA (carboxylate head) are considered long-chain PFAA as both have an eight-carbon tail. The widespread environmental presence of PFAA is attributed to the tendencies of the hydrophobic (water repelling) and lipophobic (lipid repelling) fluorinated tail (carbon-fluorine bonds) and the polar (electrostatically charged) and hydrophilic (water attracting or soluble) heads of the chemicals. Specifically, these properties lead to important partitioning mechanisms including hydrophobic effects, electrostatic interactions, and interfacial behaviors. Long-chain PFAA are more strongly sorbed and have a higher potential for bioaccumulation than short-chain chemicals (Conder *et al.* 2008). However, in general, PFAA are relatively mobile in groundwater and associate with the organic fractions of soil and sediment. PFAA are less volatile than other PFAS but can be transported in the atmosphere and can be generated by transformation of volatile precursors.

PFAA generally do not degrade or transform under ambient environmental conditions but may be formed through transformation of more volatile precursors by abiotic and biotic processes. Hydrolysis, photolysis, and oxidation have been noted to transform precursor compounds to PFAA under ambient conditions. While the PFAA group is also resistant to microbial degradation, numerous aerobic, and, to a lesser known extent, anaerobic biotransformation pathways exist to transform volatile precursors to PFAA.

Ecological and Human Health Impacts

Certain PFAS are ubiquitous in the environment due to their long-standing use in consumer, commercial, and industrial products and applications. Because the compounds are stable and mobile, they can be present in most environmental media including air, soil and sediment, groundwater, surface water, and biota (plants and animals). However, the distributions and concentrations of PFAS in environmental media are dependent on proximity to a potential source of release, nature of the source, and local geology and hydrology.

The body of literature on bioaccumulation and biomagnification of PFAS in the environment is increasing, particularly as state agencies implement their own studies. PFOS was first identified in animal tissues in the early 2000s. Giesy and Kannan (2001) quantified PFOS in fish, birds, and marine mammals in both urban and rural environments. Tissue concentrations were greater in urban environments, but the presence of PFOS in rural tissue samples indicates widespread distribution of the chemical. Subsequent studies have identified high concentrations of PFOS and other PFAA in migratory bird egg yolk (Yoo *et al.* 2008) and in resident marine organisms (Yoo *et al.* 2009) near industrial sources. Contaminant concentrations in egg yolk and soft tissue of marine organisms (blue crab) decreased as a function of distance from the source of discharge.

In recent years, states have identified high concentrations of PFOS and PFOA in filets of omnivorous and carnivorous fish near military installations and in large rivers (Michigan DEQ, 2017). PFOS and PFOA were detected in the majority of composite fish filet and liver samples representing species across multiple trophic levels and in the eggs of osprey, a piscivorous bird (WA Dept. of Ecology 2008, 2016). In the Charleston area (Harbor and tributaries) of South Carolina, PFAS were detected in all six fish species analyzed, with PFOS concentrations of certain fish species exceeding human health screening values (Fair *et al.* 2019). PFOS was the most abundant chemical detected in each fish species, representing 26-70% of the total PFAS concentration. These high PFOS concentrations across a variety of fish species indicate a high potential for bioaccumulation in human food chains. It should be noted, however, that the most recent total-dietary data (generally, from the 2016 to 2018 period) published by the US Food and Drug Administration did not reveal widespread occurrence of PFAS in surveyed foodstuffs (FDA 2020).

Because PFAS are present in the environment and in animal tissues across multiple trophic levels, these chemicals can bioaccumulate and biomagnify in humans, particularly in vulnerable or dependent populations. PFAS have been found in the blood of animals and humans worldwide and the primary non-occupational route of exposure to PFAS is diet. The United States Centers for Disease Control and Prevention (CDC) has found PFOS, PFOA, perfluorononanoic acid (PFNA), and perfluorohexane sulphonic acid (PFHxS) in the blood serum of nearly all Americans tested through the National Health and Nutrition Examination Survey (NHANES) since 1999. From 1999 to 2014 blood levels of PFOS and PFOA have declined by more than 80% and 60%, respectively, concurrent with the phasing out of these chemicals (ATSDR 2019). Further, blood serum concentrations of these chemicals have continued to decrease since 2014 (CDC 2021). However, currently used PFAS compounds not monitored in blood in this study may have replaced discontinued PFOS and PFOA. In a recent USGS study, PFAS compounds were ubiquitously detected at low levels in a tapwater survey in Chicago (Bradley *et al.* 2020) and in treated water in a national scale survey of water treatment plants (Boone *et al.* 2019).

Most studies examining the impacts of PFAS compounds on human health are cross-sectional and do not establish causality. However, the Agency for Toxic Substances and Disease Registry (ATSDR) used a weight-of-evidence approach to evaluate links between PFAS and a particular health effect (ATSDR 2018). The ATSDR draft report indicates possible associations between specific PFAS and several health outcomes:

- PFOS and PFOA – liver damage, increased total and low-density lipoprotein (LDL) cholesterol, pregnancy-induced hypertension and preeclampsia, thyroid disease, decreased antibody response to vaccines, increased risk of asthma (PFOA only), decreased fertility, and decreased birthweight
- PFHxS – liver damage and decreased antibody response to vaccines
- PFNA – increased total and LDL cholesterol
- Perfluorodecanoic acid (PFDeA) – increased total and LDL cholesterol and decreased antibody response to vaccines

Objective/Purpose of This Strategy

The objective of the Ambient Surface Water Strategy is to answer the question:

How widespread are PFAS in ambient surface waters and related aquatic media within the State of South Carolina?

The prevalence of PFAS in the environment in South Carolina is largely unknown, including in surface water and associated biota. The Surface Water Strategy will screen for PFAS in environmental media at or near locations of current and former sources that may release or may have released PFAS to the environment. Those sources include current and former industrial sites, airports, military bases, landfills, WWTPs, and agricultural fields used for land application of biosolids. This screening level program is not meant to be an exhaustive spatial characterization of PFAS in ambient waters, but a focused survey of a series of targeted locations where PFAS may occur. The results of this program will provide insights into the prevalence of PFAS in the South Carolina environment. Further, these insights, along with the results of the BOW Drinking Water Strategy, will inform future DHEC actions related to addressing possible human health and ecological impacts associated with PFAS.

At these locations, BOW will test for a group of selected PFAS in surface water and in biota using procedures and equipment that will minimize the potential for sample PFAS contamination. EPA has developed and published in 40 CFR Part 136 EPA Method 537.1 and EPA Method 533, both for drinking water. Presently, there is no analytical method validated and approved in final form by EPA and published in Part 136 of the Code of Federal Regulations (40 CFR 136 2021) for acquisition of PFAS data from non-potable water (*e.g.*, wastewater, surface water, groundwater). EPA has developed SW-846 Method 8327 for non-potable water and is moving the method through the regulatory process for ultimate publication in 40 CFR Part 136 (USEPA 2021b,d). Additionally, EPA is collaborating with DOD to validate a solid-phase extraction/isotope dilution (SPE-ID) method which will include solid matrices (*e.g.*, sediment, fish tissue) in addition to non-potable aqueous matrices (USEPA 2021d). The SW-846 Method 8327 list of PFAS compounds is expected to include a combination of 24 short-carbon chain and long-carbon chain compounds that are known to occur or possibly occur in environmental media. Length of the carbon chain and attached functional group (polar head group) influence how the compound partitions in the environment and where it may be present (*e.g.,* in dissolved form in the water column or attached to sediment).

Regulatory Overview, Other States' Efforts, and South Carolina Strategy

USEPA Health Advisories and State-level Surface Water Criteria

In 2016, EPA issued a lifetime drinking water health advisory of 70 ppt (parts per trillion, or nanograms per liter [ng/L]) for PFOS and PFOA, either individually or in combination (81 CFR 33250). A health advisory is not an enforceable standard, but is proposed to assist federal, tribal, and local managers of drinking water systems. In December 2019, EPA proposed a groundwater screening level of 40 ppt to determine if PFOS and/or PFOA are present at a site (EPA 2019). In this context, screening levels are used to determine if levels of contamination may warrant further investigation. Further, EPA adopted the drinking water health advisory (70 ppt) as a preliminary remediation goal (initial cleanup target) for groundwater that serves as a drinking water source. Some states have established drinking water regulatory, advisory, or guidance values for various PFAS. Please refer to Section II.E of the BOW Drinking Water Strategy (DHEC 2020) for a state-by-state summary of drinking water numeric limits and guidance for PFAS.

On January 19, 2021, EPA announced a final regulatory determination to proceed with regulating PFOA and PFOS under the Federal Safe Drinking Water Act by development of MCLs and to include PFAS in the upcoming Unregulated Contaminant Monitoring Rule 5 drinking water data collection (77 CFR 26072). These decisions have been reviewed by the new Presidential Administration with an announcement on February 22, 2021, of the intent to proceed with implementation of both.

To date, only Michigan, Oregon, and Colorado have promulgated surface water criteria or advisory levels for PFAS (ECOS 2020, IRTC 2020). Michigan has adopted criteria of 11 ppt for PFOS and 420 ppt for PFOA in surface waters serving as drinking water sources and 12 ppt for PFOS and 12,000 ppt for PFOA in surface waters not used as a drinking water source (MI Rule 57 R 323.1057). In 2011, Oregon adopted wastewater initiation levels for five PFAS chemicals in WWTP effluent (OAR 340-045-0100). Concentrations greater than the initiation level require a pollution prevention plan that becomes part of a facility's National Pollutant Discharge Elimination System (NPDES) permit. In July 2020, Colorado promulgated surface water standards (translation levels) largely consistent with the EPA drinking water lifetime health advisories (5 CCR 1002-31, 1002-41 2020). In addition, Florida has proposed literature-based provisional cleanup target levels and screening levels for surface water, groundwater, soil, and irrigation water (Stuchal and Roberts 2019). Provisional surface water screening levels for the consumption of freshwater and estuarine finfish and shellfish are 4 ppt for PFOS and 150 ppt for PFOA. These screening levels were developed based on human health considerations.

Studies of PFAS in Surface Water Conducted by Other States

Several states have evaluated PFAS contamination in environmental media associated with known sources of PFAS release. The following summary is not meant to be exhaustive but highlights important and pertinent findings for the development of the Surface Water Strategy.

Minnesota has conducted widespread environmental sampling in the eastern Twin Cities (Minneapolis/St. Paul) metropolitan area (East Metro). The East Metro area includes a 3M facility and multiple disposal sites as well as inactive landfills. Minnesota Department of Health (MDH) and Minnesota Pollution Control Agency (MPCA) testing identified that groundwater beneath the 3M Cottage Grove facility was contaminated with PFOA, PFOS, and perfluorobutanoic acid (PFBA). Sampling of sediments and sediment pore water near the site also revealed PFAS contamination. Further, PFAS from a 3M disposal site and an inactive landfill were found in neighboring creeks and lakes. In addition, these sites have created a large groundwater PFAS plume.

From 2009-2011, MDH and MPCA conducted a survey of PFAS concentrations in areas exposed to AFFF use. Elevated levels of PFAS were found in nearly all media including wetland surface water and sediment near the Lake Superior Emergency Response Training Center, where Class B AFFF was used until 1996. Other firefighting sites sampled as part of this study including Minneapolis-St. Paul International Airport and a Marathon refinery on the Mississippi River near St. Paul, both of which had groundwater concentrations detected below drinking water health values based on well sampling (Antea 2011).

In 2012, Michigan received a Great Lakes Restoration Initiative grant to assess and correlate PFAS concentrations in surface waters and fish across the State. The study identified concentrations of PFOS (7-50 ppt) in several large waterbodies including Flint River, Kalamazoo River, and Saginaw River as well as in bass from the Flint and Kalamazoo rivers. The highest surface water PFOS and PFOA concentrations (5,099 ppt and 1,309 ppt, respectively) were observed in Clark's Marsh, a wetland area near Wurtsmith Air Force Base (AFB). Sunfish collected from this waterbody and nearby Au Sable River yielded filet PFOS concentrations of 5,100 ppt and 166 ppt, respectively (MI DEQ 2017).

The State of Washington conducted two statewide surface water PFAS studies in 2008 and 2016 (WA Dept. of Ecology 2010, 2017). These studies quantified a suite of PFAA in surface water from several freshwater systems across the State. The 2008 study returned at least one PFAA in every Spring sample and all but two in the Fall. The highest concentrations were observed in WWTP receiving waters with little dilution. PFAA were detected in seven of 15 freshwater systems sampled in 2016. The systems with detected PFAA were those receiving a higher relative proportion of wastewater discharge and located in more developed areas, including urban lakes. In streams receiving a relatively high input from a WWTP, short-chain PFAA were dominant consistent with discharger effluent samples. PFOS was detected in 40% of composite fish filets and in 67% of composite liver samples collected as part of the 2008 study. The composite samples were dependent on fish species present at a site. In 2016, PFAS (primarily PFOS) was detected in 86% of 22 the composite fish filets and in 100% of the 22 composite liver samples analyzed. As with the fish samples, PFOS represented most of the PFAS concentration found in osprey eggs indicating communication to higher trophic level organisms (WA Dept. of Ecology 2010, 2017).

As stated previously, this summary is not meant to be exhaustive, but provides meaningful background for the development of this Strategy. Based on these studies:

- PFAS concentrations may be present in the surface water and sediment of larger waterbodies,
- the presence of PFAS in surface water and groundwater is largely dependent on how AFFF was used and managed at firefighting or fire training facilities,
- the presence of PFAS in surface water and groundwater is largely dependent on the types of industry present within the watershed,
- the presence of PFAS in surface water and groundwater is related to industrial and municipal waste storage (*e.g.,* old landfills) within the watershed,
- PFAS can be exchanged between groundwater and surface water,
- waterways receiving WWTP with low dilution and/or high urban stormwater runoff tend to have higher PFAS concentrations, and
- PFAS, particularly PFOS, are present consistently in both fish filet and liver samples with a positive relationship between concentrations in biota and in surface water.

DHEC Bureau of Water Strategy for PFAS in Drinking Water

In January 2020, BOW released the State's Strategy to assess PFAS in drinking water. Over the course of 2020, BOW began testing PFAS levels in finished water (but prior to final treatment) in all 583 community water systems within the State. Further, BOW intends to offer testing of drinking water to private well owners that are identified as potentially at-risk. Vulnerability of private wells will be assessed based on the aquifer from which the well is drawing. BOW identified the Upper Coastal Plain and Piedmont aquifers as potentially at higher risk for groundwater contamination. Private wells will be prioritized and identified based on a ranking of the potential magnitude of PFAS (in terms of concentration ranges) for each source type (Section IV.A of the Drinking Water Strategy [DHEC 2020]). Please refer to the Drinking Water Strategy for further detail.

Potential PFAS Sources in South Carolina

The BOW Drinking Water Strategy adapted a recent literature review that assessed possible relative impacts of a source type on local groundwater (Guelfo *et al.* 2018). PFAS source types and magnitudes of PFAS concentrations are highly variable, but are useful in prioritizing, generally, where potential environmental impacts could be investigated. The following list characterizes the source type and prioritization by the Drinking Water Strategy and will be used, in part, to inform the selection of Surface Water Strategy sites. Note that not all potential PFAS sources characterized in Guelfo *et al.* (2018) are directly applicable to this Strategy or South Carolina. Please refer to Section III of the Drinking Water Strategy for an expanded discussion (DHEC 2020).

Impact Rank 1: Department of Defense (DOD) and Department of Energy (DOE) Facilities

The primary source for PFAS release to the environment at DOD and DOE facilities is through the use of AFFF. PFAS have been confirmed at six facilities; results are pending or investigations are planned for four facilities; and, two sites have no documented use of AFFF (Joint Base Charleston-Weapons and Poinsett Electronic Bombing Range).

Impact Rank 2: PFAS or Fluoropolymer Manufacturing

There are no current or past facilities in South Carolina known to produce PFAS or fluoropolymer chemicals.

Impact Rank 3: Landfills

There are 677 active and inactive landfills in South Carolina. Of the total, 79 are active construction and demolition (Class 2) landfills and 28 are active municipal solid waste (Class 3) landfills. The remaining 570 landfills are inactive Class 2 (133), inactive Class 3 (228), or inactive industrial (208). There is one inactive hazardous waste landfill in Pinewood, SC.

Impact Rank 4: Airports

There are eight Part 139 airports in South Carolina. All Part 139 airports are required to have aircraft rescue and firefighting (ARFF) capabilities and are indexed from A to E (smallest to largest). The larger the airport the higher the ARFF requirements and as such Index E airports will likely have more AFFF on-site than Index A airports. South Carolina has three Index C airports (Charleston International, Greenville-Spartanburg International, and Myrtle Beach International), one Index B airport (Columbia Metropolitan), and four smaller Index A airports.

Impact Rank 5: Fire Training Areas

The South Carolina Fire Academy, a large and comprehensive fire training facility, operates a 208-acre facility north of Columbia. Before moving to its current location, the academy was located near Columbia Metropolitan airport.

Impact Rank 6: Petroleum Refineries

There are no known current or past petroleum refineries in South Carolina.

Impact Rank 7: Industrial Sites

The BOW Drinking Water Strategy identified 384 currently NPDES permitted industries that may be potential sources of PFAS to the environment. The Strategy used two criteria to assess potential industrial sources:

- process wastewater from the industry is discharged into a surface water through an 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 Standard Industrial Classification (SIC) code identified by EPA or that the BOW believes PFAS could be utilized in the production process.

The 384 industries identified in the BOW Drinking Water Strategy by SIC code are organic chemicals, plastics and synthetic fibers (OCPSF) (65), pulp and paper (11), textiles (68), and airport and other (240). Given the persistent nature of PFAS in the environment, the list of potential industrial PFAS sources was expanded to include past, or not currently, permitted facilities for this Strategy. Additionally, the list was updated to include currently permitted facilities that may not have been permitted at the time the Drinking Water Strategy was developed. Also, each facility on the list was evaluated/re-evaluated based on best professional judgement and current information regarding SIC codes that are associated with PFAS use (ASDWA 2020, NAICS 2018).

Direct Discharges

The evaluation included 684 current and terminated/closed individual industrial NPDES/ND permits. Of these, 399 were eliminated from further consideration based on SIC code or minimal flows (*e.g*., car washes). The remaining facilities include current/former OCPSF (31), textiles (81), pulp and paper (11), landfills (10), federal facilities (9), fire protection (1), and other (164). Also, there are three historic facilities which the BOW was unable to characterize based on the limited remaining information on those facilities. Note that some of the terminated/closed facilities on the individual industrial NPDES permit list may have elected to obtain coverage under a general permit (GP). The GP universe includes 25 current and terminated/closed Bulk Petroleum Storage Facility NPDES GP coverages and 2,164 current and terminated NPDES/ND GP coverages of other types (*e.g.,* mining, hydroelectric, hydrostatic test water, pesticide application, petroleum contaminated groundwater, utility water, and vehicle wash water). Of the GP coverages, Bulk Petroleum Storage Facilities is the only category being carried forward for consideration in the Surface Water Strategy as these facilities may have currently or in the past used/stored fire suppressants containing PFAS. (Note that while vehicle wash water GP discharges may contain some PFAS, they are not expected to be large contributors due to the small flows associated with these discharges.)

Pretreatment Publicly Owned Treatment Works

Pretreatment programs reduce the level of pollutants discharged by industries and other nondomestic wastewater sources into publicly owned treatment works (POTWs). The BOW evaluated 566 pretreatment facilities that discharge to municipal WWTPs. The facilities were classified into categories which include OCPSF (78), textiles (41), pulp and paper (1), landfills (9), electroplating and metals (135), and other (302). These industrial pretreatment effluents are discharged to 76 individual municipal WWTPs. The number of pretreatment discharges to individual municipal WWTPs ranges from 1-60. Overall, 59 municipal WWTPs receive between 0-9 pretreatment discharges, 12 municipal WWTPs receive between 10-19 pretreatment discharges, and two municipal WWTPs receive between 20-29 pretreatment discharges. Two other municipal WWTPs receive between 30-39 and 40-49 pretreatment discharges, respectively. The WWTP with the most receives 60 pretreatment discharges for treatment.

Impact Rank 8: Wastewater Treatment Plants

The BOW Drinking Water Strategy identified 746 WWTPs in South Carolina. Of the total, 362 are either domestic (146, privately owned) or municipal (216, publicly owned) WWTPs. The remaining 384 are industrial facilities. The PFAS composition and concentration in the effluent or sludge of an individual domestic or municipal facility is dependent on the influent to the plant (residential vs. industrial) and the activities of the influent sources.

Land Application of Treated Sludge Sites

There are more than 2,000 sites across the State that receive sludge application at some frequency associated with NPDES or ND permits. For many of these sites, especially for larger facilities, there are often multiple application fields at each site. Land application of treated sludge/biosolids is an emerging concern for the BOW. Recently DHEC detected elevated levels of PFAS in soil from a series of agricultural fields that received treated sludge from a former industrial source. Further, surface water and sediment collected adjacent to the fields contained significantly elevated levels of PFAS and nearby residential wells contained PFOS and/or PFOA concentrations greater than EPA's health advisory of 70 ppt (DHEC 2019). Private well sampling continues near some of the more than 9,800 acres that were permitted for land application from this facility.

Given the high number of WWTPs (NPDES and ND permits) in the State, it is not possible to evaluate these facilities as a whole. EPA recommends that NPDES permits include requirements for phased-in monitoring and best management practices related to PFAS when these chemicals are expected to be present in wastewater received by the WWTP (Ross 2020). As such, the Surface Water Strategy will investigate a subset of this source category, which includes the direct discharges by the industrial facilities within the priority SIC codes identified above; municipal WWTPs receiving pretreatment from industrial facilities; and, land application sites for industrial and municipal/domestic sludge (biosolids) associated with NPDES and ND permits.

Also, on January 19, 2021, based on information collected and reported in *Effluent Guidelines Plan 14* (USEPA 2021a), EPA announced the next steps the agency is taking to address PFAS in wastewater via NPDES permits issued by EPA:

- the publication of an *Advanced Notice of Rulemaking* whereby EPA intends to acquire data and information about PFAS manufacturers and the presence and treatment of PFAS in wastewater discharges from those manufacturers,
- the intent to request information regarding PFAS formulators (facilities that produce various products and materials from PFAS feedstocks), and
- interim strategy for PFAS in NPDES permits issued by EPA (USEPA 2021c).

Ambient Surface Water Assessment Plan

Assessment Design Rationale

As stated above, the objective of the Surface Water Strategy is to answer the question*: How widespread are PFAS in ambient surface waters and related aquatic media within the State of South Carolina?* The results of this assessment, along with the Drinking Water Strategy findings, will provide valuable insights into the presence of PFAS in surface waters within the State and inform future DHEC actions related to addressing possible PFAS-related human health and ecological consequences. The total number of potential PFAS sources (current and former industrial sites, airports, military bases, landfills, WWTPs, and agricultural fields) to the State's surface waters is large and the spatial distribution of these sources is vast (Table 1). As such, it is not possible to sample surface waters near each potential source.

Table 1. Distributions of potential PFAS sources by category in each South Carolina major river basin. Counts include total number of sites associated with potential sources.

	Broad	Catawba	Edisto	Pee Dee	Salkehatchie	Saluda	Santee	Savannah
DOD or DOE Sites[1]	-	-	1	3	2	2	3	1
Part 139 Airports	1	-	-	2	1	2	1	1
South Carolina Fire Academy	1	-	-	-	-	-	-	-
Landfills[2]	108	87	40	146	42	109	53	88
Industrial Sites[3]	100	46	12	90	25	73	56	116
Pretreatment POTWs[4]	18	6	2	27	7	17	8	11
Sludge Land Application Sites[5]	697	639	36	530	15	174	10	208

1: Fort Jackson occurs partly in both the Saluda and Catawba basins and the Poinsett Electronic Bombing Range/Shaw Bombing site is present in the Pee Dee, Santee, and Catawba basins.
2: Location information is unavailable for four landfills.
3: Industrial site counts represent the number of outfalls associated with the past or active NPDES permits.
4: Pretreatment POTW site counts include all NPDES permitted outfalls and ND permitted wastewater irrigation fields or lagoons associated with the pretreatment facilities.
5: Sludge land application sites include all NPDES and ND permitted sites. There may be multiple application fields associated with a permitted site.

The United States Geological Survey (USGS) divides and sub-divides the United States into successively smaller hydrologic units which are classified into four levels: regions (2-digit), subregions (4-digit), accounting units (6-digit), and cataloging units (8-digit). Below these four primary levels are the watershed (10-digit) and sub-watershed (12-digit) levels. South Carolina comprises eight major river basins: Broad, Catawba, Edisto, Pee Dee, Salkehatchie, Saluda, Santee, and Savannah (Figure 1). Within these eight major river basins are 38 8-digit cataloging units and 185 10-digit watershed units, each assigned a specific and identifying hydrologic unit code (HUC).

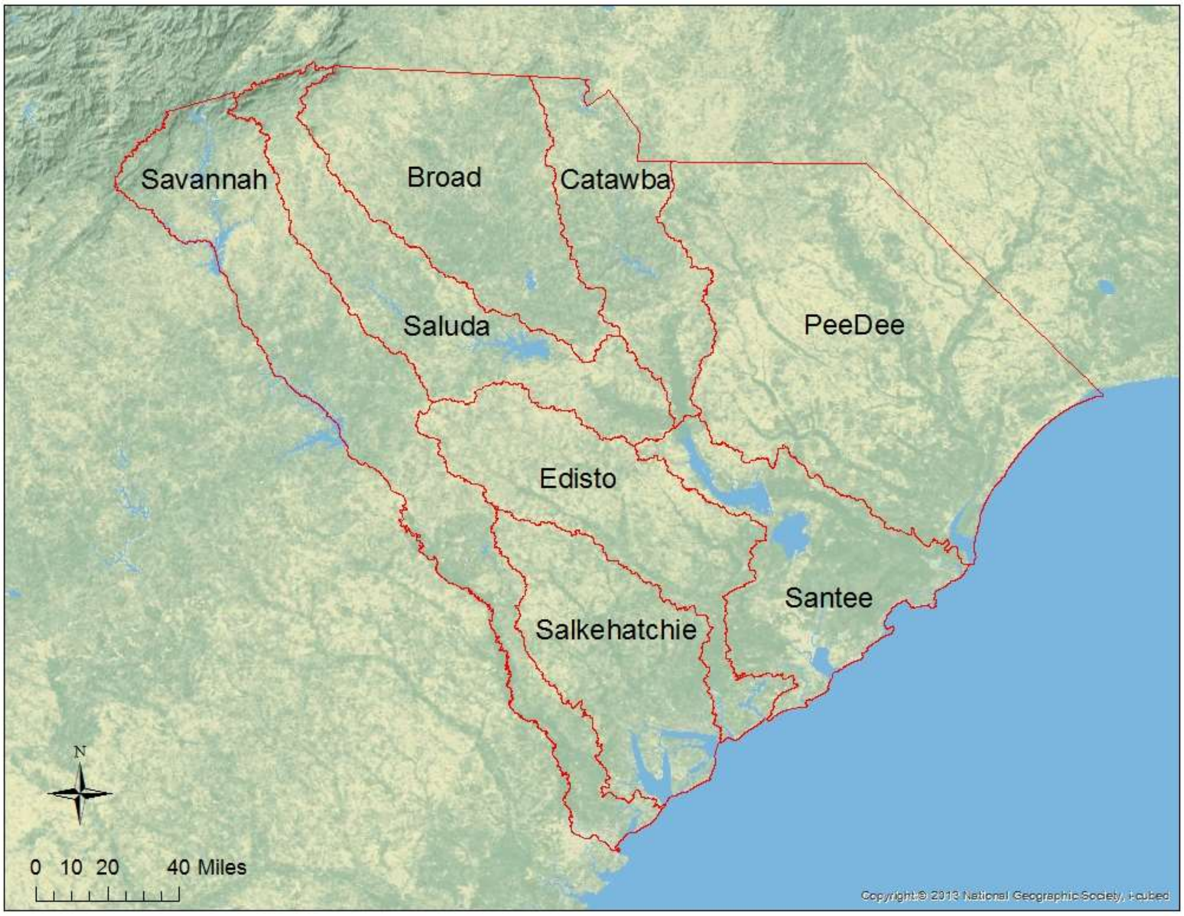

Figure 1. Major river basins in South Carolina.

The 10-digit watershed classification level (HUC-10, Figure 2) represents an ideal spatial scale from which the BOW can identify priority study areas to characterize the environmental presence of PFAS from potential release sources (Table 1). The following sections summarize how HUC-10 level watersheds were identified and prioritized related to each potential PFAS source type listed in Table 1 while considering possible impacts in each of the eight major river basins in the State. The priority study areas for each source type were then aggregated to provide a final list of target watersheds. This approach ensures that PFAS distributions from all potential source types are investigated in each major river basin in targeted watersheds where these chemicals may occur.

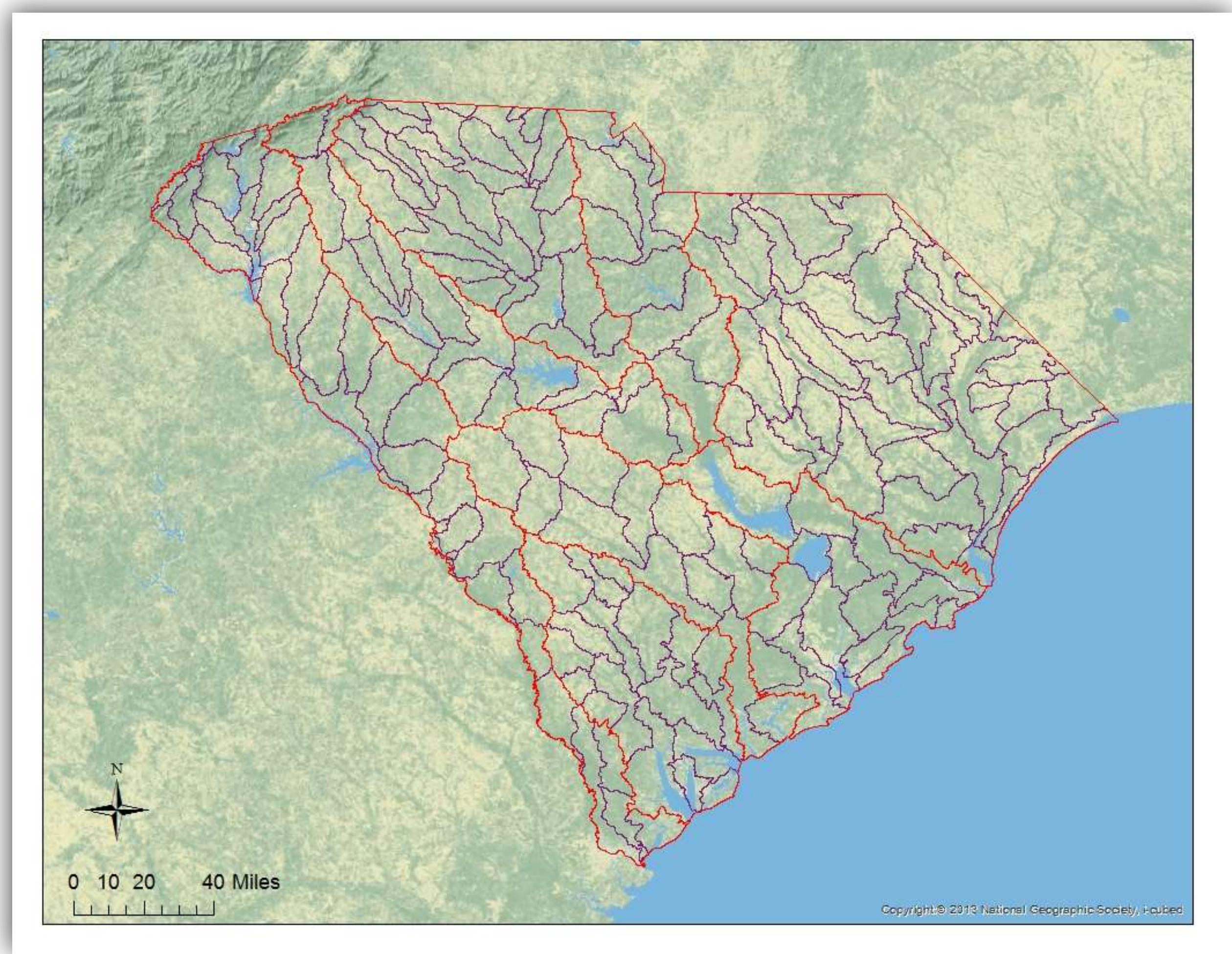

Figure 2. HUC-10 level watersheds (purple) within each major river basin. There are 185 HUC-10 level watersheds in South Carolina.

DOD and DOE facilities, Part 139 Airports, and South Carolina Fire Academy

Each HUC-10 watershed that includes a DOD or DOE site, a Part 139 airport, or the South Carolina Fire Academy is identified as a priority study area.

The DOD or DOE sites occur in parts of 14 HUC-10 watersheds across seven of the eight major river basins in the State (Broad River Basin excepted). There is considerable overlap in watersheds particularly east of Columbia at the confluence of the Saluda, Catawba, and Pee Dee basins among Fort Jackson, McEntire Joint National Guard Base, Shaw Air Force Base, and Poinsett Electronic Bombing Range. Further, Joint Base Charleston Air, Joint Base Charleston Weapons, and Charleston Naval Complex occur in two HUC-10 watersheds near Charleston (Figure 4 in Appendix A).

The eight Part 139 airports occur in eleven different HUC-10 watersheds across six major river basins (Catawba and Edisto basins excepted), however, there is overlap between the airports and the military facilities. Together, airports and DOD/DOE facilities occur in 21 watersheds with overlap between

Charleston International and the Charleston area DOD sites and between Myrtle Beach International and former Myrtle Beach Air Force Base (Figure 4 in Appendix A).

The South Carolina Fire Academy occurs in a Broad River Basin HUC-10 on the northside of Columbia. In total, the 12 DOD or DOE sites, eight Part 139 airports, and the South Carolina Fire Academy include 22 different HUC-10 watersheds (Figure 4 in Appendix A).

Landfills

For the PFAS source categories with large numbers of potential release sites (*i.e*., landfills, industrial sites, and sludge land application sites), the top two watersheds by site count for each source type in each major river basin were identified as target study areas. The top two HUC-10 watersheds by landfill count in each river basin contain approximately 32% (213) of total active and inactive landfills throughout the State. The top two watersheds in each river basin average approximately 13 landfills per watershed with a range of 8.5 (Catawba) to 18 (Santee) (Figure 5 in Appendix A).

Industrial Sites

As stated above, this Surface Water Strategy considered approximately 300 past and current permitted industrial sources as possible contributors to PFAS in the environment. These industrial discharge sources include OCPSF, textiles, pulp and paper, landfills, federal facilities, fire protection, and other. There are approximately 500 individual outfalls associated with these past and current permits. The outfalls are treated as individual sites to capture the magnitudes associated with the facilities. The top two HUC-10 watersheds by outfall count in each river basin are selected as target study areas. These watersheds make up nearly 47% of the total count of industrial outfalls. The top two watersheds average 21-22.5 outfalls per watershed in the Broad, Santee, and Savannah basins. The Edisto and Salkehatchie basins have the lowest averages at 4 and 6 outfalls, respectively (Figure 6 in Appendix A). The former Galey and Lord textile mill in Society Hill, SC (Pee Dee River Basin), is not considered as part of this Strategy as this facility is under federal Superfund (EPA) and state (Bureau of Land and Waste Management) authority.

Pretreatment POTWs

In total, there are 76 potential municipal pretreatment POTW sources (72 active NPDES facilities, one closed facility, and three ND facilities). There are 96 sites associated with these 76 sources. Each NPDES permitted outfall and ND permitted wastewater irrigation field or lagoon is identified as a site. The Pee Dee Basin includes the highest number of sites (27) and the Edisto Basin contains the fewest (2) (Figure 7 in Appendix A). As there are fewer pretreatment municipal POTWs than the other large number source categories, the top watershed by site count in each major river basin was identified as a priority study area. These watersheds include approximately 28% of the total number of pretreatment POTW sites.

Sludge Land Application Sites

The top two sludge land applications watersheds in each basin are selected as target study areas. These watersheds represent 43% (980) of the total sites throughout the State. These watersheds average approximately 61 sludge land sites though the range is large. The lowest average number of sites in the top two watersheds occur in the Santee Basin (4); the Catawba Basin has the highest average number of sites (174) (Figure 8 in Appendix A).

Summary

In total, 48 HUC-10 level watersheds were identified as target areas to address the primary objective of the Surface Water Strategy (Figure 3). The final number of watersheds indicates that there is considerable overlap among the potential PFAS source categories. A complete list of the target HUC-10 watersheds is presented in Appendix B. A specific sampling plan will be developed for each of these watersheds based on the number of potential PFAS sources and types present, source relationships to the river and stream network, size (class) of the waterways, and feasibility and accessibility of target areas. Based on these considerations, specific media (surface water and finfish/shellfish) for testing will be determined. Sample maps highlighting select watersheds, within watershed stream network, and potential PFAS sources are presented in Appendix C.

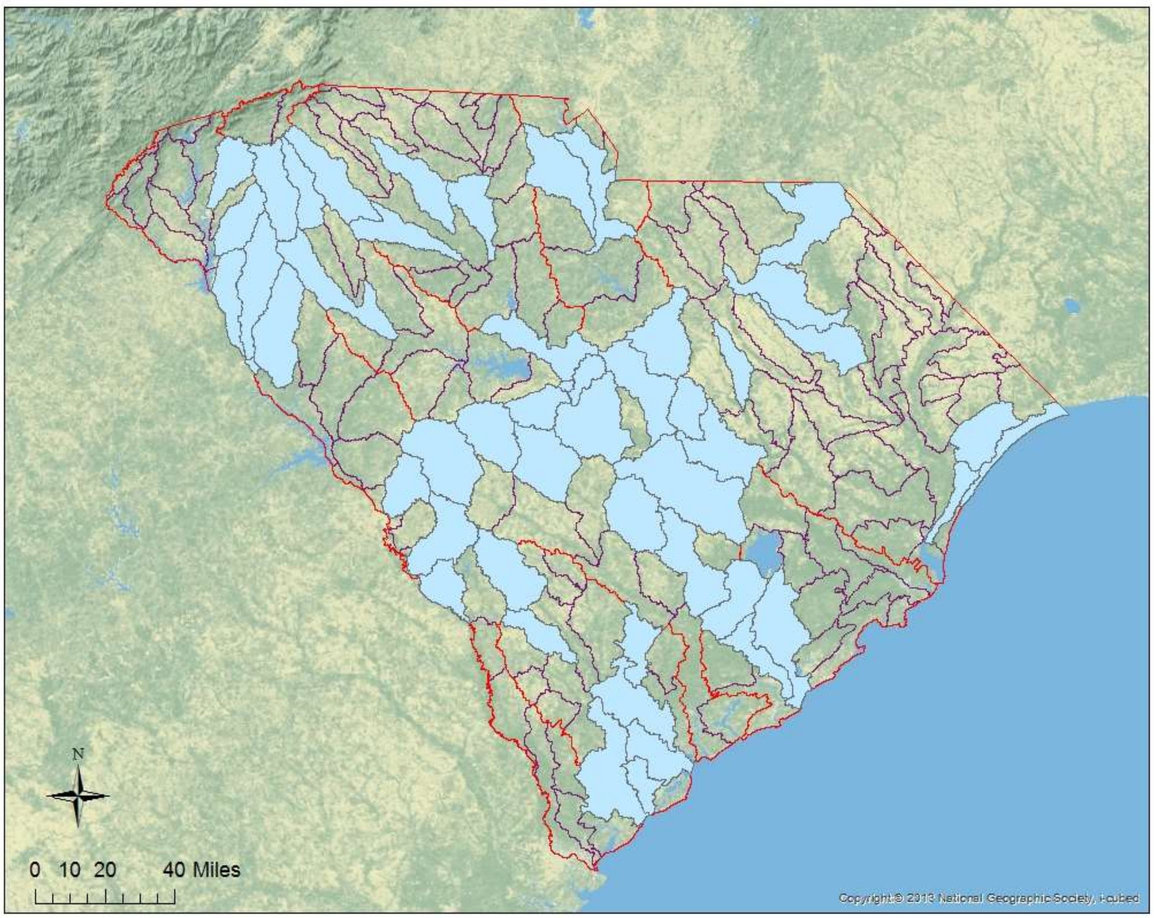

Figure 3. HUC-10 level watersheds identified as key to addressing the Surface Water Strategy's primary objective. The watersheds are distributed across each of the major river basins in SC.

PFAS of Interest

Until EPA promulgates a 40 CFR Part 136 method, a suite of target 25 PFAS or precursor compounds known to occur or possibly occur in surface water and related media has been identified for use in the Surface

Water Strategy (Table 2). This suite represents PFAS across the spectrum including both short-chain and long-chain PFAA with carboxylate and sulfonate head groups. The list also includes precursor compounds that are known to occur or may possibly occur in environmental media. The proposed EPA SW-846 Method 8327 includes 17 of the 25 target compounds. A final list of test compounds will be determined as part of study plan development and will depend on analytical capacity of the selected contract laboratory and available funding resources.

Table 2. Target list of PFAS and precursor compounds known to occur in environmental media.

Compound Name	Acronym	Surface Water	Finfish	Shellfish*
Perfluorobutanoate	PFBA	X[1]	X	X[4]
Perfluoropentanoate	PFPeA	X[1]	X[2]	X[4]
Perfluorohexanoate	PFHxA	X[1]	X[2]	X[4]
Perfluoroheptanoate	PFHpA	X[1]	X	X[4]
Perfluorooctanoate	PFOA	X[1]	X[2]	X[4,5]
Perfluorononanoate	PFNA	X[1]	X[2,3]	X[4,5]
Perfluorodecanoate	PFDA	X[1]	X[2,3]	X[4,5]
Perfluoroundecanoate	PFUnA	X	X[2,3]	X[4,5]
Perfluorododecanoate	PFDoA	X	X[2]	X[4,5]
Perfluorobutane sulfonate	PFBS	X[1]	X[2]	X[4]
Perfluorohexane sulfonate	PFHxS	X[1]	X	X[4]
Perfluorooctane sulfonate	PFOS	X[1]	X[2,3]	X[4]
Precursor Compounds				
Perfluorooctane sulfonamide	PFOSA	X	X[2,3]	X
Perfluorooctane sulfonamido acetic acid	FOSAA	X		
N-methyl perfluorooctane sulfonamido acetic acid	MeFOSAA	X		
N-ethyl perfluorooctane sulfonamido acetic acid	EtFOSAA	X		
6:2 fluorotelomer carboxylic acid	6:2 FTCA	X		
8:2 fluorotelomer carboxylic acid	8:2 FTCA	X		
10:2 fluorotelomer carboxylic acid	10:2 FTCA	X		
6:2 fluorotelomer unsaturated carboxylic acid	6:2 FTUCA	X		
8:2 fluorotelomer unsaturated carboxylic acid	8:2 FTUCA	X[1]		
10:2 fluorotelomer unsaturated carboxylic acid	10:2 FTUCA	X		
4:2 fluorotelomer sulfonate	4:2 FTS	X[1]		
6:2 fluorotelomer sulfonate	6:2 FTS	X[1]		
8:2 fluorotelomer sulfonate	8:2 FTS	X		

*to include mollusks (*e.g.,* oysters, clams) and crustaceans (*e.g.*, blue crabs, shrimp)
1: Identified in surface water (WA Dept. of Ecology 2017)
2: Identified in freshwater fish (WA Dept. of Ecology 2017)
3: Identified in estuarine or marine fish (Fair *et al.* 2019)
4: Identified in freshwater aquatic invertebrates (Koch *et al.* 2019)
5: Identified in blue crabs or other marine invertebrates (Yoo *et al*. 2009)

Media

Three media have been identified as key to addressing the Surface Water Strategy's objective: surface water, finfish, and shellfish. These media have been selected to provide insights into the relationship between the water column and ecologically and economically important species on a PFAS specific basis. Testing for a subset of PFAS in fish and shellfish communities will establish a basic, first order, mechanistic link between PFAS in the water column and the resident aquatic faunal community. Quantifying these distributions will inform the BOW on partitioning tendencies between the water column and food webs for each PFAS compound and how each of these chemicals' properties influence how they interact with the South Carolina environment. This understanding will be enhanced by further resolving water chemistry (discussed below). This relationship is not meant to fully resolve trophic transfer or bioaccumulative tendencies of PFAS but to provide the BOW a sound basis from which to investigate questions related to human health consequences or ecological integrity.

Other Supporting Aquatic Chemistry

The primary objective of this study is to determine how widespread PFAS are in the surface water and related media (aquatic life). Water chemistry influences PFAS exposure and uptake by animal and plant life. To provide insights on exposure pathways between surface water and aquatic life, dissolved organic carbon, total organic carbon, hardness, alkalinity, water temperature, and pH will be determined in water samples collected at the same time as PFAS sampling. This PFAS site-specific stream data will bolster the State's historical ambient monitoring program data and provide a basis for understanding bioaccumulation tendencies which bear on human health and ecological integrity.

Timeline

Stream flows, hydrology, and geochemical conditions (*e.g.*, water temperature, dissolved oxygen, pH) in South Carolina exhibit seasonal trends and are related to prevailing climate and seasonal weather patterns. In general, winter conditions tend to result in higher rainfall totals, increased stream flows, lower water temperatures, and higher dissolved oxygen levels, while summer weather tends to be drier and warmer which yields reduced stream flows, warmer water temperatures, and lower dissolved oxygen levels. These seasonal differences in weather impact stream flushing, stream metabolic rates and assimilation capacity of organic matter, and stream chemistry. As such, each target watershed will be sampled at least once between November and February to characterize PFAS distributions and supporting chemistry during winter conditions and at least once between March and October to characterize the summer conditions. The total number of sampling events in each watershed will be determined based on funding availability and preliminary laboratory results.

Field Sampling and Laboratory Analyses

All field sampling will be conducted following approved DHEC field sampling methods or prevailing best practices that will be memorialized in an approved Quality Assurance Project Plan. Biological tissue (finfish, mollusks, and crustaceans) analyses will follow USFDA Method C-010.01 or other equivalent and appropriate method.

Path Forward and Next Steps

Adaptability and Implementation Schedule

The BOW intends that the Surface Water Strategy outlined here represents a framework from which to develop a specific sampling plan. Ultimately, the sampling plan will be guided by watershed feasibility analyses, which includes an understanding of the relationships between potential PFAS sources and local stream networks. The local stream network will inform which types of media will be investigated (*e.g.,* stream size, freshwater vs. marine/estuary settings). The total number of sampling sites will be determined from watershed feasibility studies and anticipated availability of resources. The BOW reserves the right to alter the Surface Water Strategy as new information or updated guidance becomes available.

The BOW's Surface Water Strategy will be implemented along the following timeline:

Second Quarter (April-June) 2021

- Finalize and publish this Strategy
- Prepare quality assurance project plan
- Prepare procurement for external laboratory services

Third Quarter (July-September) 2021

- Finalize quality assurance project plan
- Award procurement for external laboratory services

Fourth Quarter (October-December) 2021

- Prepare for winter sampling program component

First Quarter (January-March) 2022

- Conduct winter sampling program component
- Update DHEC website with laboratory and field results
- Prepare for summer sampling program component

Second Quarter (April-June) 2022

- Conduct summer sampling program component
- Update DHEC website with laboratory and field results

Third Quarter (July-September) 2022

- Continue summer sampling program component
- Update DHEC website with laboratory and field results

Fourth Quarter (October-December) 2022

- Finalize 2022 field sampling
- Update DHEC website with remaining data

First Quarter (January-March) 2023

- Prepare study final report and update website

Communications

The BOW commits that the results of the Surface Water Strategy will be communicated in a timely, consistent, and transparent manner. Throughout the implementation of this Strategy, BOW will communicate with the public through a Surface Water PFAS Strategy webpage that will be developed and maintained on the BOW webpage. This communication process will include regular updates on sample results. A final report and/or summary of findings will be posted on the webpage following conclusion of the field program and sample analyses. PFAS are currently not regulated contaminants. As such, DHEC's role at this time is to make the public aware of the data obtained as part of this Strategy and to provide information and education about PFAS compounds in the aquatic environment.

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Appendix A – Maps of Potential PFAS Sources

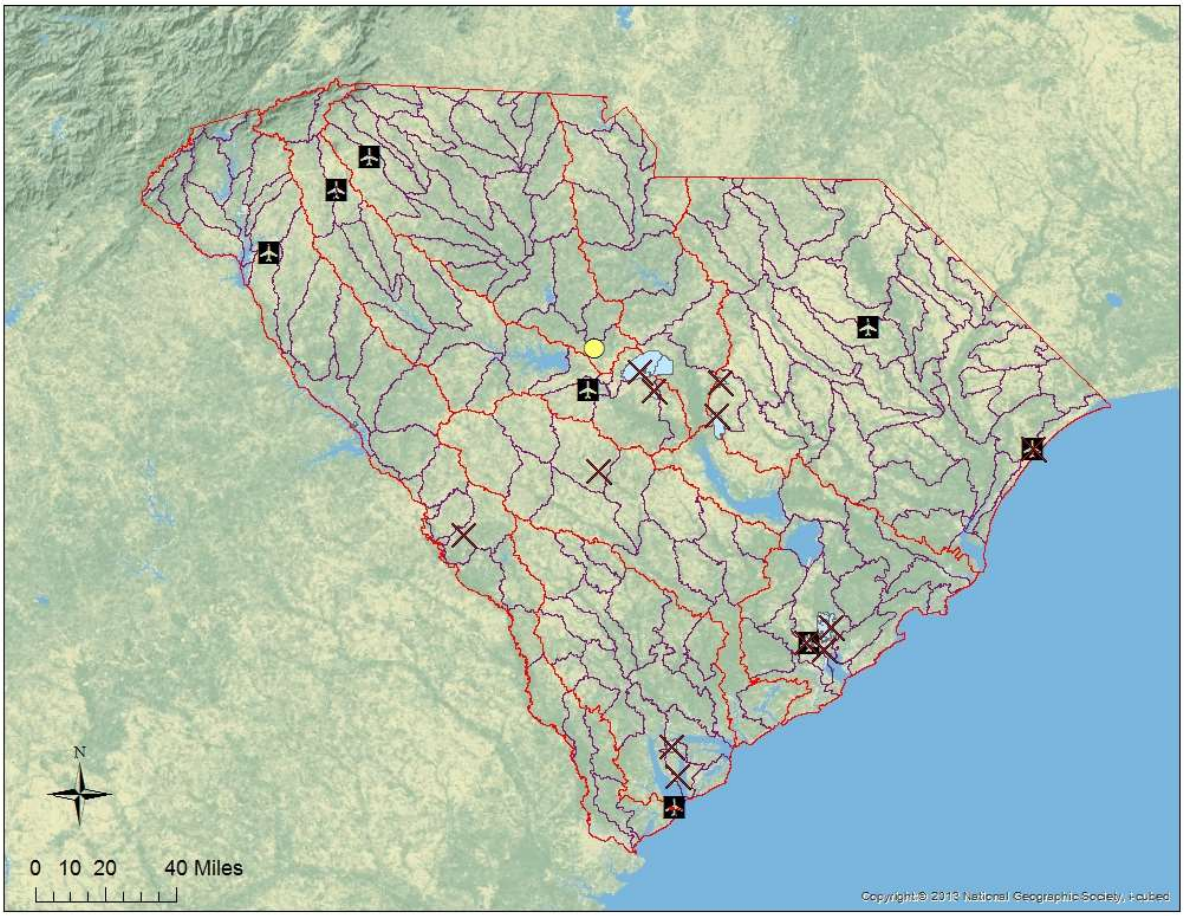


Figure 4. Distributions of Department of Defense and Energy facilities (x-symbols), Part 139 airports (airplane symbols), and South Carolina Fire Academy (yellow circle). Current and former military facilities are co-located with airports in Charleston and Myrtle Beach. Perimeters of select military bases are indicated by the blue polygons.

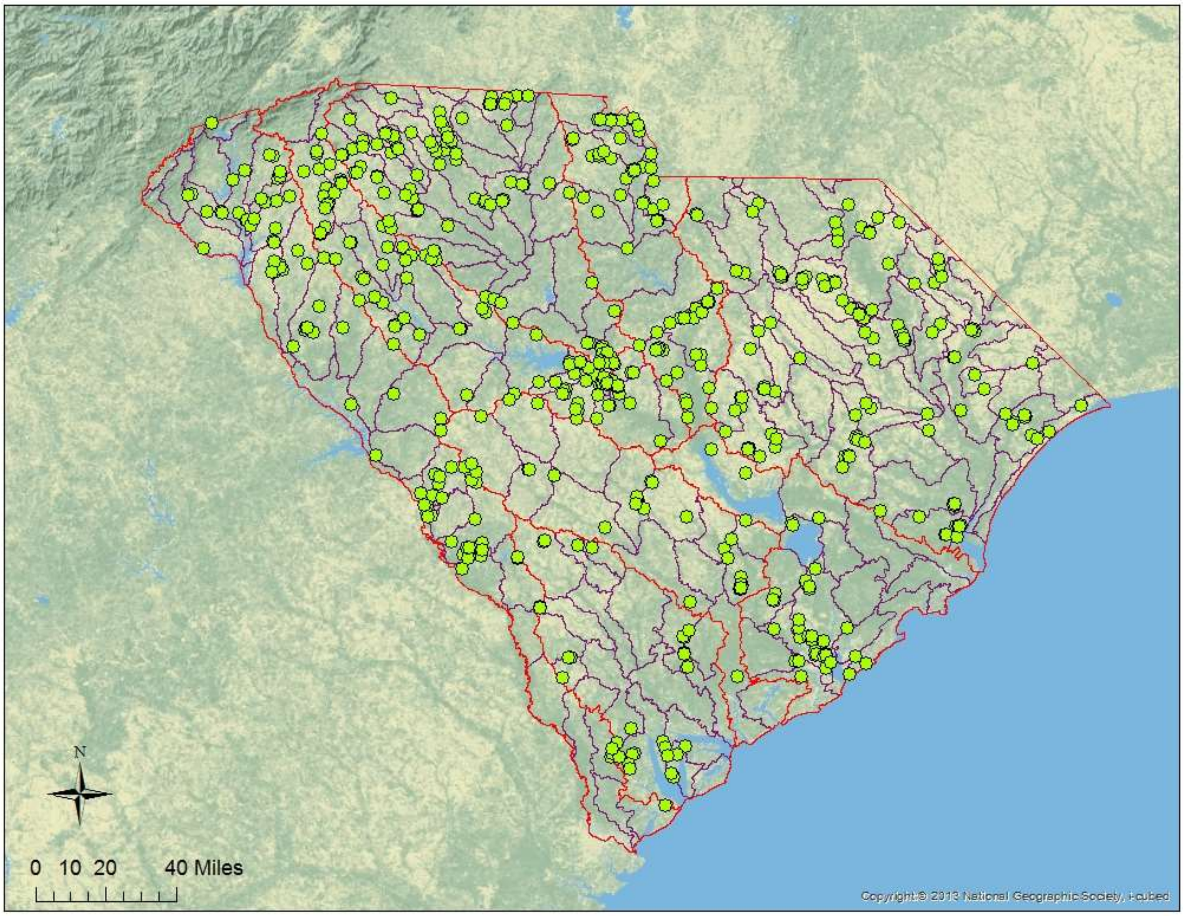


Figure 5. Distribution of active and inactive landfills across South Carolina.

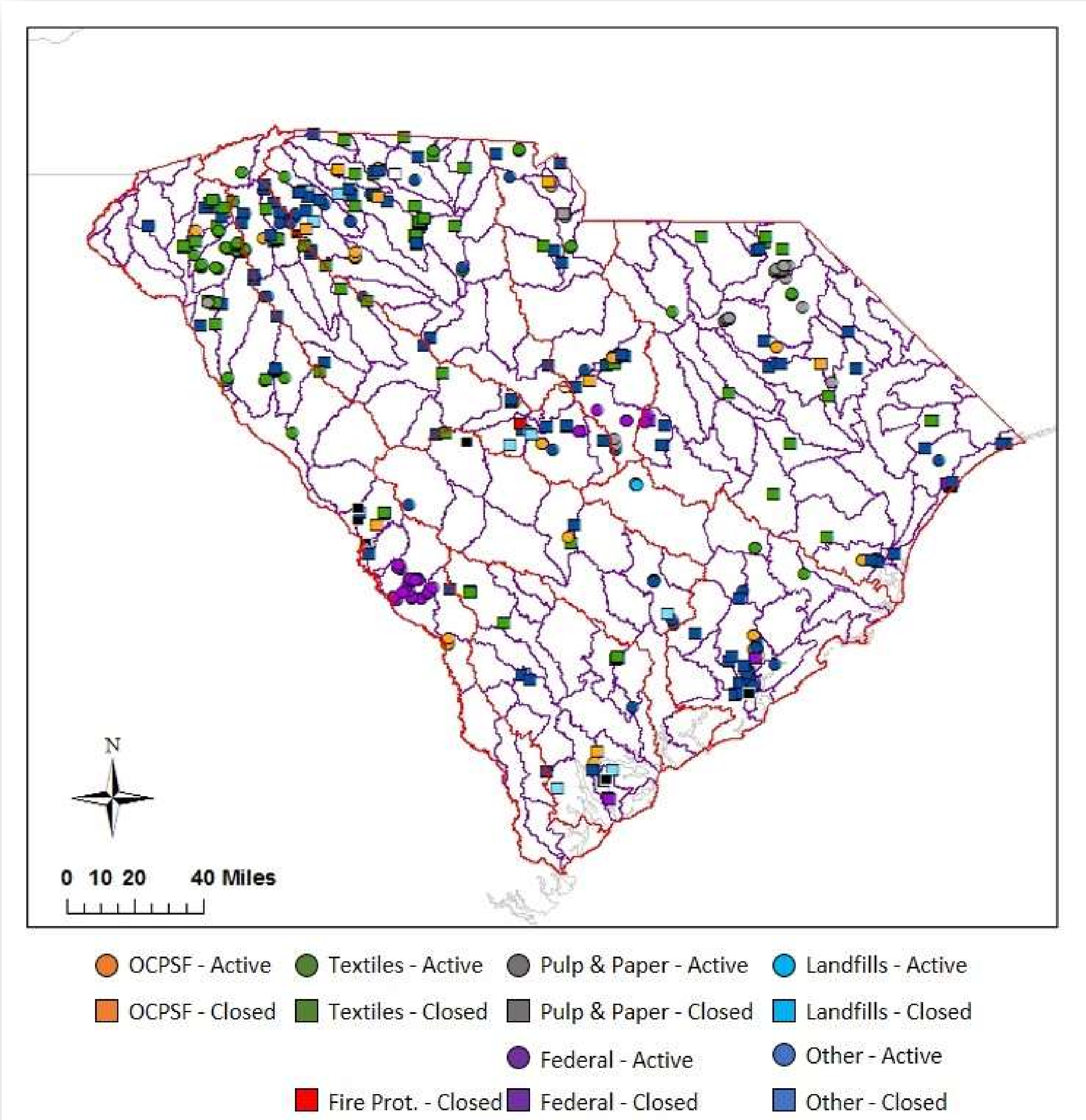


Figure 6. Distributions of active and closed NPDES outfalls by industrial category. Background map was removed to highlight the variety of industrial source types.

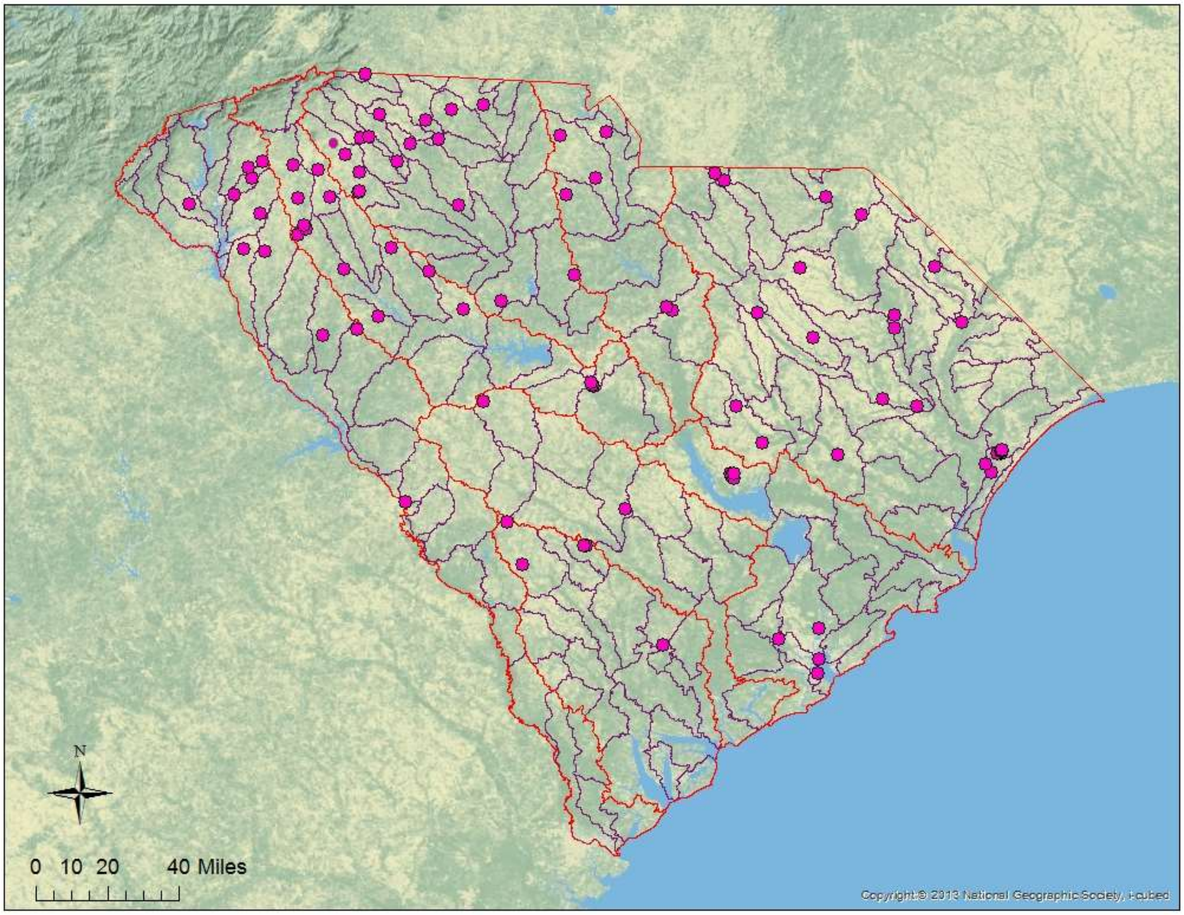


Figure 7. Distribution of publicly owned treatment works receiving industrial pretreatment. Map includes all active permitted NPDES outfalls and active permitted ND wastewater irrigation fields and lagoons. One recently closed POTW in Greenville County is also included.

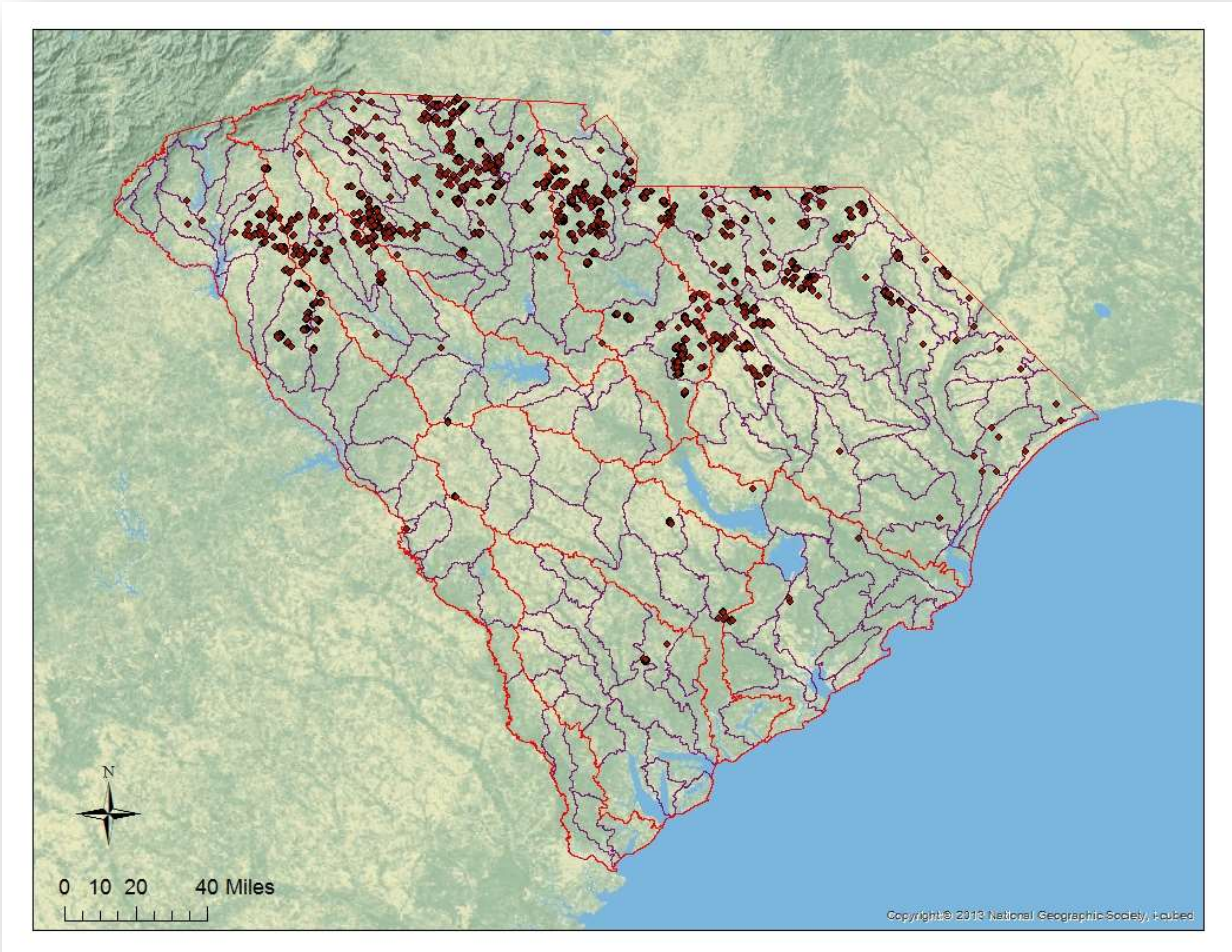


Figure 8. Distribution of land application sludge sites associated with NPDES or ND permits across South Carolina.

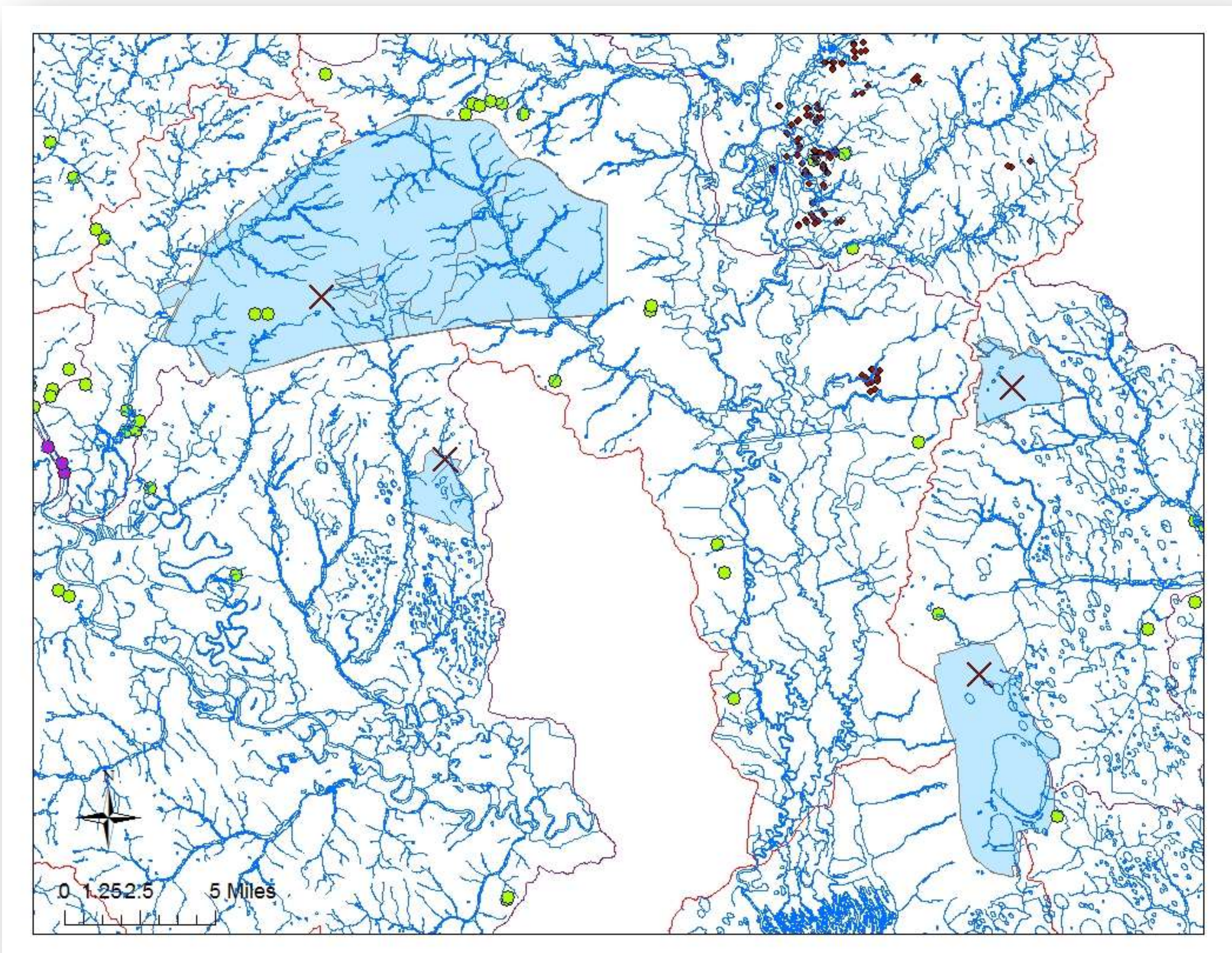
Appendix B – List of Target HUC-10 Watersheds

HUC-10	HUC-10 Name	Basin
03050106-03	Browns Creek-Broad River	Broad
03050106-07	Crane Creek-Broad River	Broad
03050107-04	Fairforest Creek	Broad
03050108-01	Upper Enoree River	Broad
03050108-02	Middle Enoree River	Broad
03050103-04	Fishing Creek	Catawba
03050103-06	Fishing Creek Reservoir-Catawba River	Catawba
03050104-03	Middle Wateree River	Catawba
03050104-04	Lower Wateree River	Catawba
03050203-01	Upper North Fork Edisto River	Edisto
03050203-02	Middle North Fork Edisto River	Edisto
03050204-01	Upper South Fork Edisto River	Edisto
03050205-01	Upper Four Hole Swamp	Edisto
03050205-03	Lower Four Hole Swamp	Edisto
03040201-05	Reedys Branch-Great Pee Dee River	Pee Dee
03040201-07	Lower Black Creek	Pee Dee
03040201-09	Jeffries Creek	Pee Dee
03040205-02	Headwaters Black River	Pee Dee
03040205-03	Cane Savannah Creek	Pee Dee
03040205-04	Pocotaligo River	Pee Dee
03040206-09	Socastee Swamp-Waccamaw River	Pee Dee
03040206-10	Outlet Waccamaw River-Atlantic Intracoastal Waterway	Pee Dee
03040208-03	Little River	Pee Dee
03050207-01	Headwaters Salkehatchie River	Salkehatchie
03050207-02	Whippy Swamp	Salkehatchie
03050207-07	Combahee River	Salkehatchie
03050207-08	Upper Ashepoo River	Salkehatchie
03050207-11	Coosaw River-Port Royal Sound	Salkehatchie
03050208-05	Beaufort River-Atlantic Intracoastal Waterway	Salkehatchie
03050208-06	Broad River-Port Royal Sound	Salkehatchie
03050109-03	Grove Creek-Saluda River	Saluda
03050109-04	Upper Reedy River	Saluda
03050109-08	Lake Greenwood-Saluda River	Saluda
03050110-01	Congaree Creek	Saluda
03050110-02	Gills Creek	Saluda
03050110-03	Cedar Creek-Congaree River	Saluda
03050111-01	Lake Marion-Santee River	Santee

HUC-10	HUC-10 Name	Basin
03050201-05	Cypress Swamp	Santee
03050201-06	Ashley River	Santee
03050201-07	Cooper River	Santee
03060101-04	Twelvemile Creek-Keowee River	Savannah
03060101-07	Three and Twenty Creek	Savannah
03060103-02	Rocky River	Savannah
03060103-04	Big Generostee Creek-Savannah River	Savannah
03060103-05	Little River-Savannah River	Savannah
03060106-02	Horse Creek	Savannah
03060106-05	Upper Three Runs	Savannah
03060106-08	Steel Creek-Savannah River	Savannah

Appendix C – Example Maps of Selected HUC-10 Watersheds

Example map of several target HUC-10 level watersheds with associated stream networks. Map highlights the military bases east of Columbia (Fort Jackson, McEntire Joint National Guard Base, Shaw AFB, and Poinsett Electronic Bombing Range) and a cluster of sludge land application sites (brown diamonds) in the Middle Wateree River HUC-10. Landfills are scattered throughout the area (green circles) and a few pretreatment POTWs are located in the Cedar Creek-Congaree River watershed on western edge of the frame. Note: map does not include industrial sites.



Example map highlighting a high density of sludge land application sites in two HUC-10 watersheds (Fishing Creek and Fishing Creek Reservoir-Catawba River) in the northern region of the Lower Catawba River Basin. Note: map does not include industrial sites.