Historical Reconstruction of **Per- and Polyfluoroalkyl Substance (PFAS) Concentrations**

Pease International Tradeport, New Hampshire Water System

Condensed Report

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Based on Final Report by Abt Associates

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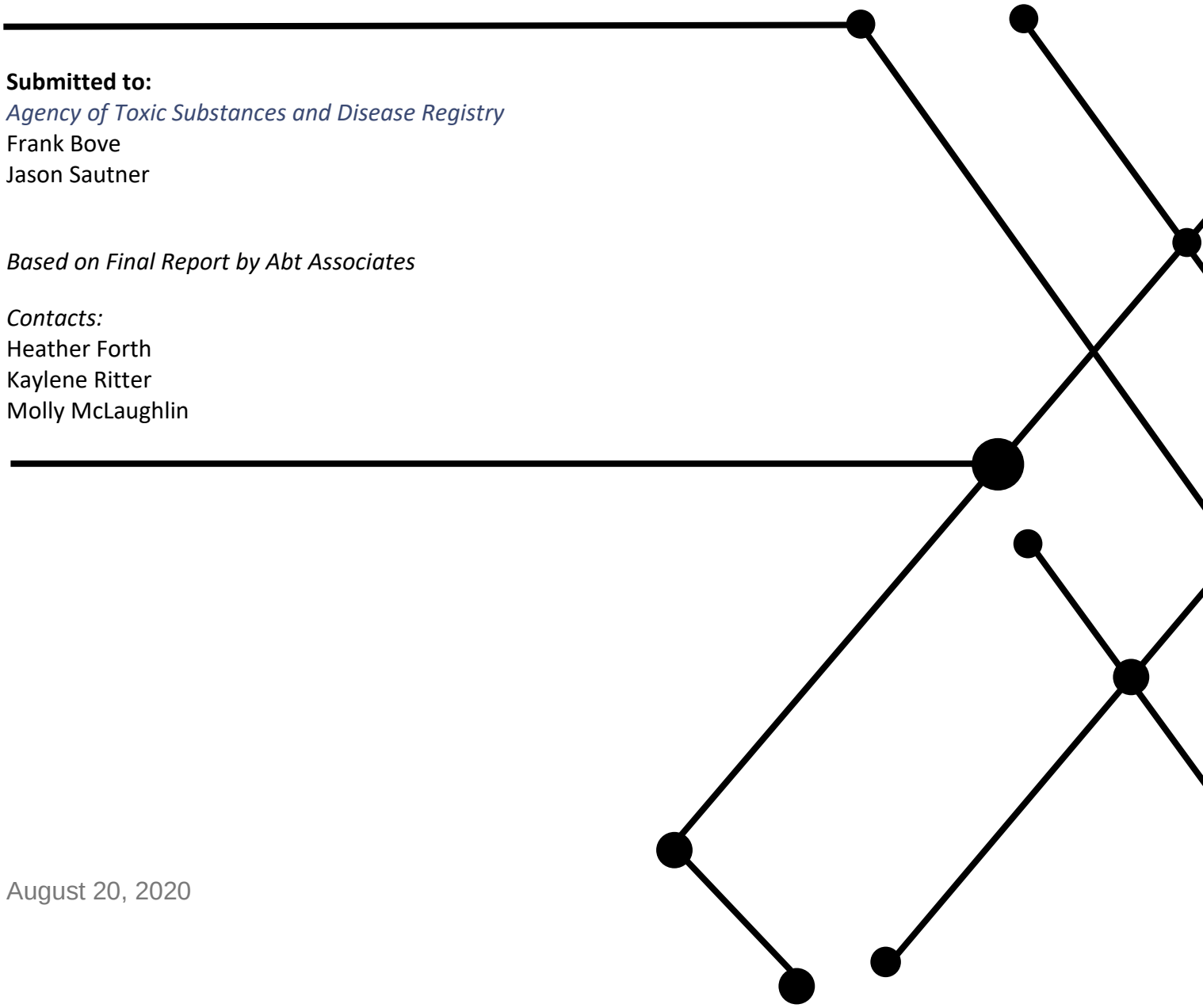

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IV. Acronyms and Abbreviations

1D	One-dimensional
2D	Two-dimensional
Abt	Abt Associates
ADE	Advection-dispersion equation
AFFF	Aqueous film-forming foam
AFHRA	Air Force Historical Research Agency
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
ARFF	Aircraft Rescue and Firefighting
ATSDR	Agency of Toxic Substances and Disease Registry
DoD	Department of Defense
EPA	U.S. Environmental Protection Agency
ETA	Equipment Testing Area
FD	Fire Department
FTA	Fire Training Area
IRP	Installation Restoration Program
NHANG	New Hampshire Air National Guard
NH	New Hampshire
PDA	Pease Development Authority
Pease site	Pease International Tradeport
Pease Water System	Pease International Tradeport Water System
PFAS	Per- and polyfluoroalkyl Substance
PFHxS	Perfluorohexanesulfonic Acid
PFNA	Perfluorononanoic Acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctanesulfonic Acid
PFSA	Perfluorosulfonic Acid
TCE	Trichloroethylene
USAF	U.S. Air Force
WWTF	Wastewater Treatment Facility

1. Introduction

The Agency of Toxic Substances and Disease Registry (ATSDR) is currently assessing potential human health impacts resulting from per- and polyfluoroalkyl substances (PFAS) contamination of the public water system at the Pease International Tradeport (herein "Pease"), formerly a U.S. Air Force (USAF) base in Portsmouth, NH. Shortly after the base closed in 1991, the site reopened as a mixed-use office complex employing over 10,000 people (PDA, 2018).

During operations at the former USAF base, PFAS-containing aqueous film-forming foam (AFFF) was used as a fire extinguisher, resulting in the contamination of soil, groundwater, and the Pease International Tradeport Water System (herein Pease Water System). In 2013, groundwater sampling at a former Fire Training Area (FTA) at the northern end of the site, where AFFF was frequently used, detected elevated levels of PFAS (CB&I, 2015). This triggered sampling of the three groundwater wells that supplied the Pease Water System at the time – the Haven, Harrison, and Smith wells, which showed:

- **Haven Well:** In 2014, PFAS concentrations, specifically perfluorooctanesulfonic acid (PFOS), were an order of magnitude higher than the Environmental Protection Agency's (EPA) provisional health advisory in place at the time (i.e., 0.2 µg/L) (EPA, 2009; Amec Foster Wheeler, 2016a). The well was closed immediately and the EPA since lowered the advisory to 0.07 µg/L (EPA, 2016a).
- **Smith and Harrison Wells:** (located downgradient of the Haven well), PFAS was detected at levels below the EPA's provisional advisory (Amec Foster Wheeler, 2016a).

As a part of a recent Health Consultation, ATSDR made estimates of PFAS concentrations in the Pease Water System from 2003 to 2015 using a flow-weighted, simple mass-balance mixing model (ATSDR, 2019). This model requires two inputs: 1) pumping rate and 2) PFAS concentration at each well over the modeled time period. The timeframe was selected based on the start year of the earliest, most complete pumping record that ATSDR could obtain. PFAS concentrations were set as constant values throughout that period, given the lack of specific measured concentrations prior to 2014.

ATSDR aimed to determine whether the model could be refined by historically reconstructing past PFAS concentrations at the site based on an analysis of PFAS sources and pathways. Given significant site uncertainties and data gaps, ATSDR convened an Expert Panel to determine whether historical reconstruction at Pease was possible and, if so, recommend how to complete it. ATSDR worked with contractors (Abt Associates and Guidehouse) both to convene the panel and develop the final model.

To develop the model, Abt reviewed the recommendations of the expert panel as well as site history (including AFFF-related activities). Abt compiled information on the water system; evaluated available PFAS chemistry in soil and groundwater; and, where possible, modeled groundwater flow and contaminant transport from key PFAS sources. Abt then used a simple

mixing model and monthly averaged pumping data for each of three supply wells (and Portsmouth water booster percentages) to estimate PFOS and other PFAS concentrations.

This abridged report provides a description of these modeling activities and presents a summary of the results and findings. It is intended for audiences who may have information to fill in data gaps relating to AFFF release at six source areas. The full report includes a more detailed description of the hydrogeologic setting, modeling approach, methods, and assumptions used, the groundwater model verification effort, and the modeling results from the historical reconstruction of PFAS in the Water System. The full report is available upon request.

2. Project Objectives and Scope

The goal of this effort is to reconstruct historical PFAS concentrations in the Pease Water System by refining ATSDR's simple mixing model (ATSDR, 2019). Specific objectives include:

- Review available data on PFAS source areas, concentrations and transport pathways;
- Develop/verify approaches to simulate transport of PFAS from source areas to wells;
- Conduct unsaturated zone/groundwater transport modeling from key source areas to wells;
- Organize existing data and fill in data gaps regarding water inputs to the water supply;
- Apply a simple mass-balance mixing model to estimate drinking water concentrations in the Pease Water System from 1993 to 2014;
- Identify and describe important information gaps on the sources of PFAS contamination and on the transport pathways from the sources to the Pease supply wells (**Table 1**).

Table 1. Persisting Data Gaps on Sources of PFAS Contamination at the Pease International Tradeport by Site

Source Areas	Data Gaps
Site 8	• What amount of AFFF concentrate was typically used in a training event? • What was the total volume of AFFF released? • Which formulation(s) of AFFF were used over time? • By what means was AFFF contamination transported to the south of the current groundwater divide? • What were the historical pumping rates for the Haven Well (e.g., during the 1970s and 1980s)?
Former Crash Fire Station	• What was the earliest year that AFFF releases/spills could have occurred? • What were the timing, quantity, and/or nature of AFF spills/releases that occurred outside the station? • Did releases/spills typically occur on the paved surface or were they washed off the paved surface into nearby grassy areas?
KC-135	• What formulation of AFFF was used to extinguish the fire?

Fire Department (FD) Equipment Testing Area (ETA)	• What was the volume of AFFF released? • When did AFFF releases occur? • When did the New Hampshire Air National Guard (NHANG) Fire Department (FD) transition from using the North Apron to using the FD ETA to test and calibrate equipment?
North Apron	• When did the NHANG FD transition from using the North Apron to using the FD ETA to test and calibrate equipment? • How often did equipment testing and/or calibration activities occur? • How much AFFF typically was released during these testing and/or calibration activities? • Where within the North Apron area did testing and/or calibration activities occur?
Flight Line Storm Sewer System	• Where did leaks of AFFF occur in the drainage system? • How much AFFF was released through drainage leaks?

3. Background on PFAS and AFFF

3.1 What are PFAS?

PFAS are a group of manmade chemicals composed of a partially or fully fluorinated carbon chain, which can be attached to different functional groups and include varying amounts of oxygen, hydrogen, and nitrogen. They are generally characterized as being resistant to degradation by acids, bases, heat, or oxidants (Field et al., 2017). As a result, PFAS are extremely persistent in the environment, which means they can accumulate in environmental media and the human body over time. Exposure to certain PFAS has been found to cause adverse human health effects (EPA, 2016a, 2016b; ATSDR, 2018). PFAS have been manufactured and used in a variety of industries since the 1940s (3M, 2020). They are found in many common household items, including cleaners, paper, and paints; and they serve as waterproof coatings for textiles such as furniture, carpet, leather, and outerwear. They are also a major component of AFFF, which is used to suppress and prevent fuel-based fires at military bases, fire departments, airports, refineries, and other facilities across the country (Darwin, 2004). AFFF, which is also used for training, is the main source of PFAS at Pease.

3.2 AFFF Use at Military Facilities

The Department of Defense (DoD) began purchasing AFFF in the early 1970s for use at military installations across the county, where it was primarily used for fire suppression and prevention and during fire training activities (Darwin, 2004). PFAS are the primary active ingredients in AFFF. Based on the results of an inventory of current AFFF use and stocks in the United States commissioned by the Fire Fighting Foam Coalition in 2004, the primary brand of AFFF used at U.S. military installations was 3M Lightwater, dominated by PFOS, Perfluorohexanesulfonic acid (PFHxS), other Perfluorosulfonic acids (PFSAs), and PFSA precursors (Darwin, 2004). When used, AFFF is diluted with water, which produces an aqueous film that extinguishes the flame. The USAF primarily uses a 3% AFFF concentrate (Field 2017).

3.3 PFAS Included in Historical Reconstruction

For the historical reconstruction at the Pease International Tradeport (Pease site), we focused on three PFAS: PFOS, Perfluorooctanoic acid (PFOA), and PFHxS because:

- To date, PFOS and PFOA are the most prevalent chemicals from the PFAS group in the environment with demonstrated adverse human health effects.
- PFOS and PFHxS are primary constituents of the AFFF formulations most often used by the USAF.
- PFOS is one of the main PFAS contaminating Pease public wells.
- PFHxS is found in the Pease public supply wells at elevated concentrations.
- Though PFOA was detected at significantly lower concentrations on average, there are certain areas of Pease where PFOA is the dominant PFAS.
- Drinking water health advisories for PFOS and PFOA have indicated that their effects of are additive so both must be considered when evaluating concentrations and human health effects.

While Perfluorononanoic acid (PFNA) was also detected at elevated levels (although considerably lower than PFOS, PFOA and PFHxS) it was determined that it is not feasible to include it in the reconstruction at this time. PFNA is not a detectable constituent in any AFFF formulations, making it difficult to estimate the amount released. We hypothesize that the presence of PFNA at Pease is related to the degradation of precursor compounds found in AFFF; however, scientific understanding of these precursors and how they degrade is limited and therefore not easily quantifiable.

4. Site Description and History

4.1 Site Description

Pease is a 4,255-acre site located in the coastal region of NH between the City of Portsmouth and the towns of Newington and Greenland. The site is located on the Newington peninsula approximately five miles west of the Atlantic Ocean. It is surrounded by water: Piscataqua River to the east (which drains to the Atlantic Ocean), Little Bay to the north, Great Bay to the west, and Great Bog (which ultimately drains to Great Bay) to the south.

4.2 General Site History

While Pease was a USAF base (1956–1991), the site was home to the 100th and 509th Bombardment Wings. In 1966, the New Hampshire Air National Guard (NHANG) relocated the 157th Military Airlift Group to Pease.

As part of USAF base closures across the country, the Pease base closed in 1991. In 1993, the site reopened as the Pease International Tradeport, which consisted of a mix of commercial spaces, including businesses, industrial offices, restaurants and two child-care centers. Currently, businesses at the Pease site employ over 10,000 people (PDA, 2018). In addition, the NHANG still operates out of Pease today as an air refueling group.

In 1983, environmental investigations began under the Air Force Installation Restoration Program (IRP) to evaluate and clean up the contamination at the USAF base related to site operations. These initial investigations discovered chlorinated solvents, petroleum hydrocarbons, and metal contamination in site soils and groundwater, which led to Pease being added to the National Priorities List in 1990.

As part of the investigation on three emerging contaminants (i.e., PFOS, PFOA, and 1,4-dioxane), groundwater samples were collected in June and September 2013 in the Fire Training Area (FTA) referred to as FTA-2 (or Site 8) located in the northern end of the former base (CB&I, 2014). This investigation was the first to detect elevated PFAS concentrations in the groundwater at Site 8. Specifically, PFOA (up to 120 µg/L) and PFOS (up to 95 µg/L) were measured in groundwater at levels several orders of magnitude higher than EPA's provisional health advisory levels, which at the time were 0.4 µg/L and 0.2 µg/L, respectively (EPA, 2009). EPA's health advisory level has since been lowered to 0.07 µg/L for PFOS and PFOA combined (EPA, 2016a, 2016b). These

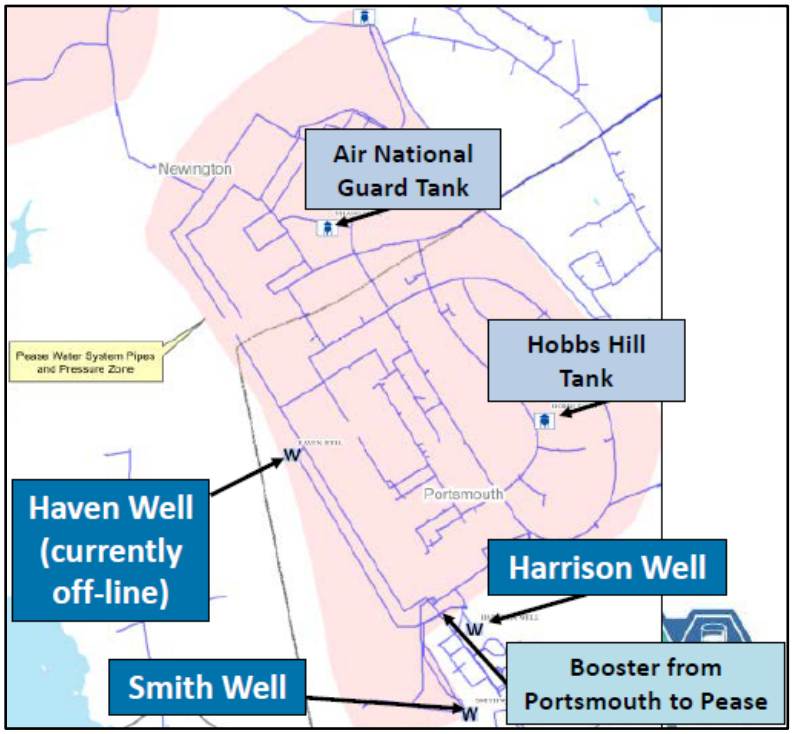
concentrations are also well above NH state-established maximum contaminant levels in 2019 for PFOA (0.012 µg/L) and PFOS (0.015 µg/L). The state has also recently set levels for PFHxS (0.018 µg/L) and PFNA (0.011 µg/L) (NHDES, 2019; City of Portsmouth Department of Public Works, 2020).

Findings at Site 8 triggered sampling of the three groundwater wells that supplied the Pease Water System at the time: the Haven, Harrison, and Smith wells. In May 2014, the Haven well was shut down when PFOS was measured at 2.5 µg/L (Goetz, 2018). PFAS compounds were also detected in the Smith and Harrison wells, albeit below advisory levels.

4.3 Pease Water System

The Pease Water System was built in the 1950s for the Pease USAF. Ownership was turned over to the PDA (Pease Development Authority) in the early 1990s and has been operated by the City of Portsmouth since 1992 (Rice and Goetz, 2015). The Pease Water System has three water supply wells: Haven, Smith, and Harrison (**Figure 1**). Installed in 1875, the Haven well predates the Pease Water System, while the Smith and Harrison wells were installed in 1957.

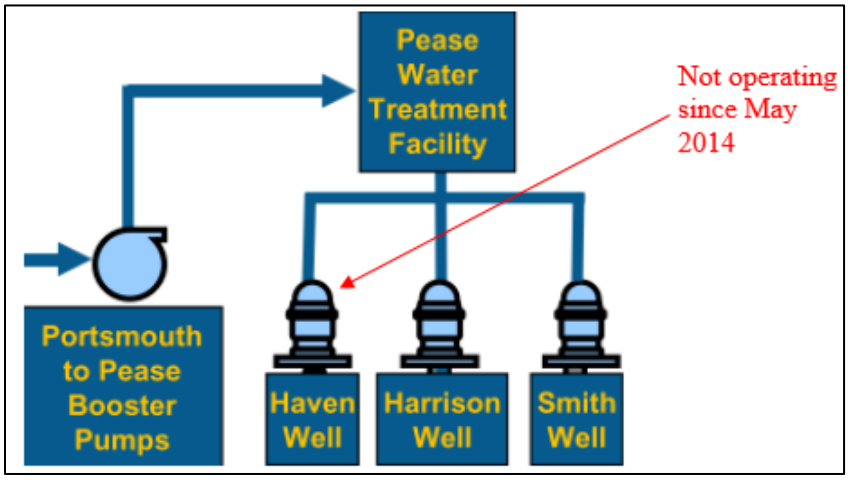
Figure 1. Pease Water System. (Source: City of Portsmouth, 2017.)



The Harrison well did not produce water, nor did it operate as a supply well until 2006, when it was retrofitted by the City of Portsmouth. In addition, a booster was installed in the 1990s to

allow water to be pumped between the neighboring Portsmouth Water Supply System and the Pease Water System. Boosted water from the Portsmouth Water Supply System has supplied approximately half of the Pease Water System demand since the Haven well was shut down due to PFAS contamination in May 2014. Prior to that time, water was boosted from Portsmouth only as needed to meet demand. Currently, groundwater from the Smith and Harrison wells and the Portsmouth Booster are all pumped to the Grafton Road Water Treatment Facility (installed in 1985), where the water is blended and supplied to the Pease Drinking Water Distribution System (Rice and Goetz, 2015). Two water tanks, the Air National Guard and the Hobbs Hill tanks, are used to pressurize the system for distribution. **Figure 2** provides a conceptual diagram of the water supplies pumped into the Grafton Road Water Treatment Facility.

Figure 2. Conceptual diagram of water supplies pumped into the Grafton Road Water Treatment Facility. (Source: Modified from Rice and Goetz, 2015.)



5. Conceptual Site Model

This section presents the overall conceptual site model for the Pease site, including: general descriptions of how AFFF and/or PFAS were released; potential pathways for transport of PFAS from both primary and secondary sources to groundwater (our primary source of concern); and a conceptual understanding of contaminant transport through groundwater to the public wells.

5.1 Types of Releases

Previous investigations have found elevated concentrations of PFAS in soils and groundwater at multiple locations across the Pease site (CB&I, 2015, 2017; Amec Foster Wheeler, 2017a), confirming that PFAS were released during site activities. To identify areas where PFAS-containing AFFF might be present, Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) (2015) conducted research into how and where AFFF was used, stored, handled, or accidentally released. This investigation identified the following general types of AFFF releases at the site:

- General AFFF use (i.e., fire training activities, fire suppression and prevention events, and equipment testing).
- Spills during handling (e.g., AFFF transfer to Aircraft Rescue and Firefighting (ARFF) vehicles.
- Leakage from storage containers.
- Accidental releases from equipment or fire suppression systems.
- AFFF residue release related to equipment and truck-washing activities.

In addition to these primary source areas, Amec Foster Wheeler identified several types of secondary sources, which is an area or source that serves as another point of release (i.e., an outfall or a sink), where contaminants released from primary sources accumulate. Potential secondary sources at the site include:

- Leakage from storm and sewer drainage systems (which may also be pathways).
- Leakage from landfills that received AFFF- and PFAS-contaminated waste.
- Drainage system and wastewater treatment facility (WWTF) outfalls.
- Redistribution of contaminated groundwater to surface soils (e.g., recharge trenches, irrigation systems, tap water use).
- Sediments in waterbodies that received PFAS contamination from other sources.
- See **Section 6** for descriptions of specific areas where these different types of releases reportedly occurred at the site.

5.2 Pathways to Groundwater

The focus of this conceptual site model is on PFAS pathways to groundwater. A primary pathway to groundwater is the direct release of AFFF to soils. PFAS from contaminated soils may then travel through the vadose zone (i.e., the unsaturated zone of the soil column above the water table) into groundwater, transported by water infiltrating from the surface (e.g., precipitation). PFAS can then be transported through groundwater toward public supply wells. Some of the PFAS released at the surface may be adsorbed by the soil and then continue to leach downward to the groundwater. This can occur over time periods that can extend beyond the timeframe of the original releases at the surface.

Within some areas of Pease, particularly paved or concrete surfaces, AFFF may have been collected by stormwater, sewer, and/or other drainage systems, which could then have rapidly

transported AFFF toward discharge points such as outfalls, or the WWTF. The Flight Line Storm Sewer System was designed to collect runoff from the flight line and adjacent facilities, and this runoff was directed to the MacIntyre outfall, which is reached by a storm sewer line that crosses the site directly at the Haven well. Different portions of this system are above and below the water table. The culverts or pipes that make up these drainage systems are not impenetrable and were, in fact, designed to be leaky, causing them to serve as a potential pathway to the underlying soil and to groundwater at locations where the pipes are above the water table. The reverse-flow direction occurs for sections of the sewer line positioned below the water table, with groundwater flowing into the pipe, rather than piped water leaking out to the surrounding soil. Leakage may occur at regularly spaced joints in the drainpipes. It may also occur directly through culverts, as a result of partial dissolution of the concrete material (USGS, 1982).

Overland dispersion of AFFF is another potential contamination pathway at the site. Given that the finished foam is a relatively light substance that is typically sprayed 10 ft or more into the air, it has been suggested that the AFFF could occasionally be blown hundreds of feet from the release point. This overland dispersion can effectively extend the boundaries of the primary source area. PFAS that is transported on the surface from a source area prior to infiltrating into the ground may then follow different groundwater pathways and end up in locations that would not be predicted based on an evaluation of groundwater pathways directly from the original release site.

Other pathways to groundwater include percolation of precipitation through PFAS-contaminated waste materials disposed of in onsite landfills and the redistribution of contaminated groundwater from one source area to another due to remedial activities (re-injection of groundwater) or irrigation systems. This report (and, consequently, the resulting model) focuses mainly on the vadose zone pathway, though it does discuss (qualitatively) the potential implications of the Flight Line Storm Sewer System pathway. While we acknowledge that other pathways such as those discussed above may have occurred at Pease, we have insufficient data and information to include them in the historical reconstruction. All of these pathways, and as they relate to AFFF and/or PFAS releases at different source areas, are discussed in more detail in **Section 6**.

5.3 Transport to the Public Supply Wells

Once PFAS reach the water table, they are transported by groundwater. The water table at Pease typically mimics surface topography thus flow direction is generally from higher to lower topography. Depending on the location of the source area and where the PFAS reaches the water table, groundwater flow may or may not be directed toward public supply wells. For many source areas, groundwater flow is in one general direction that is dictated by groundwater elevations. However, in some cases, source areas are adjacent to or straddle a groundwater divide (e.g., Site 8, FD ETA) and, consequently, contamination from the source area may flow in multiple directions depending on where within the source area the PFAS

contamination infiltrated. For these areas, a slight shift in the groundwater divide (i.e., in response to changes in physical parameters such as changes in precipitation and infiltration, and, in particular, pumping rates of nearby water supply wells) may alter the direction of groundwater flow and, thus, affect potential PFAS pathways between source areas and public supply wells.

6. PFAS Source Areas

This section provides a brief summary of all 23 potential PFAS sources identified to date. For each source, we evaluated the likelihood that it is a contributor to PFAS contamination in public water system wells (based on soil and groundwater PFAS measurements); groundwater flow directions and pathways; and the timeline of known AFFF use.

This review narrowed down the likely sources of PFAS to the Pease Water System to six key sources. We complete this section by providing a more detailed analysis of these six key source areas, including an assessment of our ability to model PFAS transport from these source areas based on the level of available data and information.

6.1 Identifying Potential PFAS Source Areas

In 2015, a preliminary assessment of potential PFAS source areas at Pease (Amec Foster Wheeler, 2015), using information from interviews of base personnel, online research, site visits, and a review of archival materials at the Air Force Historical Research Agency (AFHRA) and the Air Force Safety Center. This process identified 21 potential areas where AFFF or AFFF-contaminated wastewater or groundwater was released, used, or stored. Based on our review of existing site data and discussions with the Expert Panel, we identified and evaluated two additional areas, namely Sites 22 and 37 west of the flight line and the onsite landfills. Descriptions of each of these potential source areas, including a timeline of AFFF-related activities, are provided in **Table 2**. **Figure 3** shows a map of the potential source areas at the Pease site.

Table 2. List of potential AFFF source areas, a description and timeline of AFFF-related activities at each area, and summary results from an initial review regarding the source area's potential to contribute PFAS contamination to Pease public supply wells.

Map No.	Source Area Name	Timeline of AFFF Presence	Source Area Type	Description of AFFF-Related Activity	Contributed to Contamination in Public Supply Wells?	Reason
1	Site 8	1974–1988	Documented AFFF release	Site 8 was used for fire training and ARFF equipment calibration and testing, with confirmed releases of AFFF at the site.	Yes; major	Potentially a significant PFAS source to public supply wells
2	Former Crash Fire Station	1974–2006	AFFF handling and storage; no documented release	Area was used for AFFF storage and truck washing. In addition, AFFF was transferred into ARFF vehicles at the site. According to interviews, there were no documented AFFF releases at the site and all released AFFF would have been collected by the building sewer system and routed to the WWTF, which was closed in 2006.	Yes; major	Potentially a significant PFAS source to public supply wells
3	North Apron	1988–unknown	Documented AFFF release	Area was used for ARFF equipment calibration and a testing area after closure of Site 8. Interviews confirm discharge of AFFF at the site.	Yes; minor	Potentially a minor PFAS source to public supply wells
4	FD ETA	Unknown	Documented AFFF release	Area was used for ARFF equipment calibration and a testing area with confirmed discharge of AFFF at the site.	Yes; major	Potentially a significant PFAS source to public supply wells
5	KC-135 Accident Area	January 11, 1990	Documented AFFF release	An estimated 90,000 gal. of AFFF and water were used to extinguish a fire that occurred in this area.	Yes; major	Potentially a significant PFAS source to public supply wells
6	Hangar 253	1992 and 1995	Documented AFFF release and storage	The facility maintained an AFFF fire suppression system from 1992 through 2005; with AFFF releases in 1992 and 1995, when an unknown quantity of AFFF was released into the storm sewer and onto the grass east of the area.	No	Unlikely source due to low PFAS concentrations
7	Hangar 254	1992	Documented AFFF release and storage	The facility maintained an AFFF fire suppression system, with an AFFF release during installation in 1992, where	No	Unlikely source due to low PFAS concentrations

Table 2. List of potential AFFF source areas, a description and timeline of AFFF-related activities at each area, and summary results from an initial review regarding the source area's potential to contribute PFAS contamination to Pease public supply wells.

Map No.	Source Area Name	Timeline of AFFF Presence	Source Area Type	Description of AFFF-Related Activity	Contributed to Contamination in Public Supply Wells?	Reason
				an unknown quantity of AFFF was released into the containment system and routed to the WWTF.		
8	Tank Farm	1993–2012	AFFF storage; no documented release	An AFFF fire suppression system was installed after the base closure; however, the system was never tested or utilized, and no AFFF was released.	No	Unlikely source due to lack of pathway
9	Golf Course Maintenance Area	Unknown	AFFF storage; no documented release	The facility stored AFFF in 55-gal. drums; however, no AFFF releases were documented.	No	Unlikely source due to low PFAS concentrations and lack of pathway
10	Firing Range Area	2006	Documented AFFF release	An unknown quantity of AFFF was released north of the firing range.	Yes; major	Potentially a significant PFAS source to public supply wells
11	Supply Building 122	Unknown	AFFF storage; no documented release	The facility reportedly stored AFFF; however, no AFFF releases were documented.	No	Unlikely source due to low PFAS concentrations and lack of pathway
12	Pease International Tradeport WWTF	Unknown	Received AFFF wastewater	Records and interviews indicated a hangar AFFF release would have been collected and routed to the Pease International Tradeport WWTF by the sanitary sewer system.	No	Unlikely source due to lack of pathway
13	Pease International Tradeport WWTF Outfall	Unknown	Released AFFF wastewater	Records and interviews indicated a hangar AFFF release would have been collected and routed to the WWTF by the sanitary sewer system. Discharge of the WWTF was at this location.	No	Unlikely source due to lack of pathway
14	Flight Line Storm Sewer System	Unknown	Transported AFFF wastewater	Records and interviews indicated a release of AFFF on the flight line would have been collected and routed to the storm sewer outfall at the McIntyre Brook via this pipeline system.	Yes; major	Potentially a significant PFAS source to public supply wells

Table 2. List of potential AFFF source areas, a description and timeline of AFFF-related activities at each area, and summary results from an initial review regarding the source area's potential to contribute PFAS contamination to Pease public supply wells.

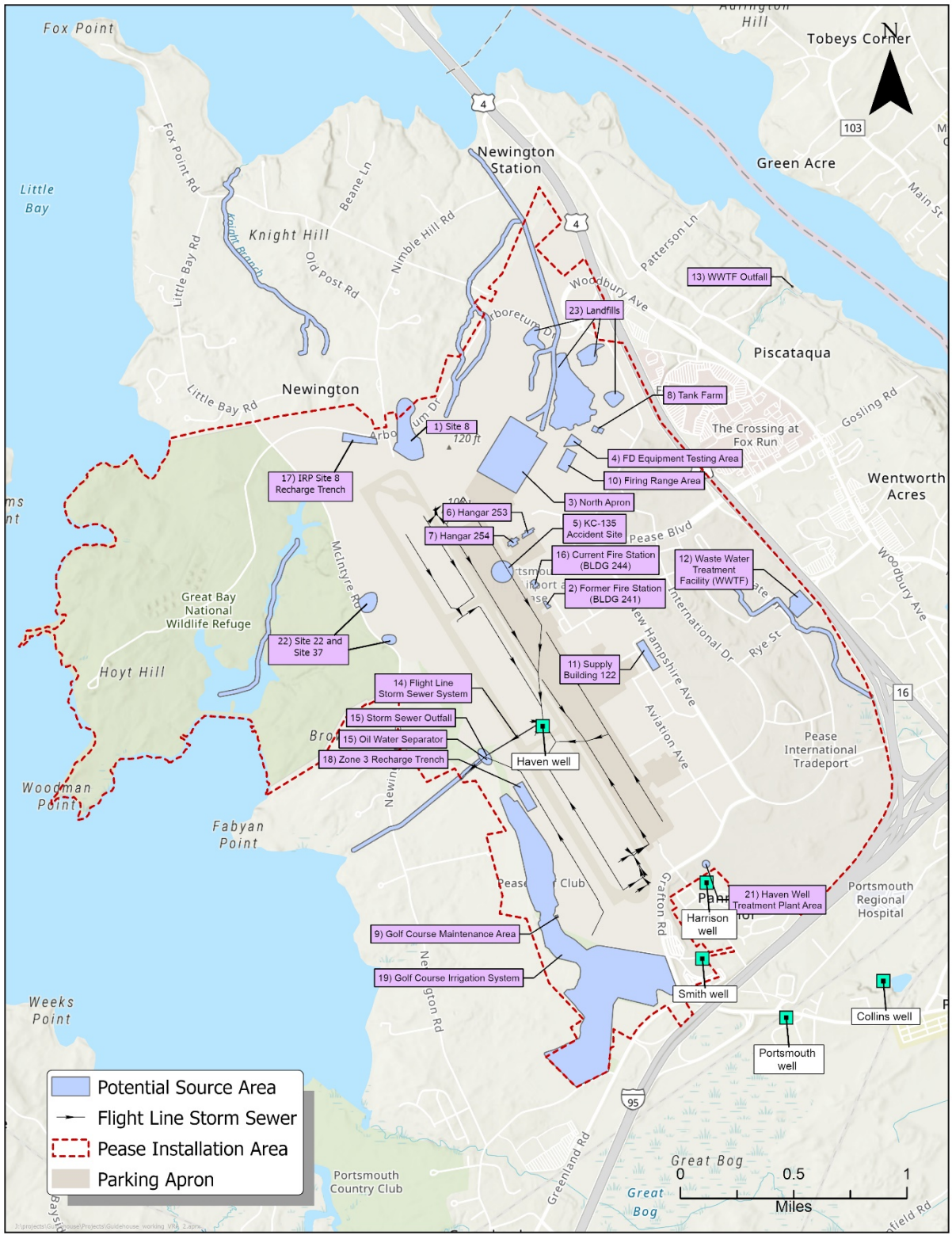
Map No.	Source Area Name	Timeline of AFFF Presence	Source Area Type	Description of AFFF-Related Activity	Contributed to Contamination in Public Supply Wells?	Reason
15	Flight Line Storm Sewer Outfall	Unknown	Released AFFF wastewater	Records and interviews indicated a hangar AFFF release would have been collected and routed to the WWTF by the sanitary sewer system and discharged at this location.	No	Unlikely source due to lack of pathway
16	Current Crash Fire Station	2006–present	AFFF storage; no documented release	The facility stored AFFF in two 850-gal. mobile trailers; however, no AFFF releases were documented.	No	While high PFAS concentrations are observed near this source area, likely from KC-135
17	IRP Site AT008 Recharge Trench	1995–present	Received AFFF-contaminated groundwater	The treatment system has been in operation since 1995, and AFFF in soils and groundwater at Site AT008 could have been transported to the recharge trenches.	No	Unlikely source due to lack of pathway
18	Zone 3 Recharge Trench	1997–present	Received AFFF-contaminated groundwater	The treatment system pumping system could have extracted groundwater containing AFFF and transported it to the recharge trench.	No	Unlikely source due to low contamination and dominant pathway away from public supply wells
19	Golf Course Irrigation System	1997–present	Received AFFF-contaminated groundwater	The treatment system pumping system could have extracted groundwater containing AFFF and transported it to the irrigation system.	No	Unlikely source due to low PFAS concentrations
20	Hodgson Brook	1992	Received AFFF-contaminated groundwater	Discharge location of PFAS-contaminated groundwater from the 1992 Haven well aquifer test.	No	Unlikely source due to low PFAS concentrations and lack of pathway
21	Haven Well Treatment Plant Area	2002–2014	Received AFFF-contaminated groundwater	Discharge location of PFAS-contaminated groundwater from the 2002–2014 Haven well safe yield and flow test, which was 100 ft east of the Haven Well Treatment Plant and 475 ft upgradient of the Harrison well.	Yes; minor	Potential source of low-level PFAS contamination to the Harrison well

Table 2. List of potential AFFF source areas, a description and timeline of AFFF-related activities at each area, and summary results from an initial review regarding the source area's potential to contribute PFAS contamination to Pease public supply wells.

Map No.	Source Area Name	Timeline of AFFF Presence	Source Area Type	Description of AFFF-Related Activity	Contributed to Contamination in Public Supply Wells?	Reason
22	Sites 22 and 37	1974–1976	Potential AFFF release	In a letter to the State of NH, the USAF identified Site 22 as a potential PFAS source area due to fire training activities that reportedly occurred between 1954 and 1976 (CB&I, 2014).	No	Unlikely source due to low contamination and dominant pathway away from public supply wells
23	Onsite landfills	Unknown	Potentially received AFFF-contaminated wastes	Site landfills received a variety of site-related wastes, which potentially included PFAS-contaminated wastes.	No	Unlikely source due to lack of pathway

According to an interview with Kory Skalecki, Pease transitioned from protein-based AFFF to fluoro-based AFFF in 1974. Other documents indicate use began in 1970 (Amec Foster Wheeler, 2016b, 2017a).

Figure 3. Potential PFAS Source Areas



6.2 Assessment of Potential PFAS Source Areas

To determine whether any of the potential PFAS source areas posed a risk to the Pease water supply wells we:

- Evaluated PFAS concentration data to determine the level of contamination at each area
- Assessed groundwater transport
- Reviewed the timeline of known AFFF-related activities

Upon completion of this review, we conducted a more detailed analysis of the narrowed down list of source areas that emerged from the assessment. A summary of the results is provided in **Table 2**, with source area activity descriptions and timelines.

6.2.1 PFAS Concentration Data Review

We reviewed available PFAS chemistry from soil and groundwater samples collected across the site to assess contamination at the 23 potential PFAS source areas. Note that for some source areas, our assessment was based on limited data and, as such, more comprehensive sampling could impact our conclusions, especially if additional contamination is discovered. Using the data available, we assigned each potential source area a high, low, trace, or unknown contamination category based on PFOS, PFHxS, and PFOA concentrations measured from soil and/or groundwater collected within or in proximity to the source area (**Table 3**). The ranges for these categories are provided in **Table 4**. Source areas with trace levels of contamination in and around the area were considered unlikely to be sources of contamination to public water supply wells and were not further considered in the historical reconstruction. These included Hangar 253, Hangar 254, the Golf Course, the Golf Course Maintenance Area, Supply Building 122, the Zone 3 Recharge Trench, and the Current Crash Fire Station (**Table 3**).

Ruling out these seven source areas left 16 source areas with high, low, or unknown levels of contamination, which could potentially be a source of PFAS contamination to public supply wells.

Table 3. Summary of Results from PFAS Source Area Assessment: Average Range of PFAS found in Groundwater (GW) and Soil (S)

Map No.	Source Area Name	Number of Samples	PFOS		PFHxS		PFOA		Contamination Level Category
			Groundwater (µg/L)	Soil (µg/kg)	Groundwater (µg/L)	Soil (µg/kg)	Groundwater (µg/L)	Soil (µg/kg)	
1	Site 8	GW = 18 S = 12	0.03–140 (27.4)	ND–600 (61.0)	1.8–31 (12.3)	0.2–300 (37.6)	0.8–120 (20.7)	ND–160 (22.1)	High
2	Former Crash Fire Station	GW = 3 S = 4	0.49–19 (6.8)	5.4–300 (113)	0.2–6.3 (2.4)	1–54 (16)	0.03–1.5 (0.6)	0.3–10 (3.5)	High
3	North Apron	GW = 6 S = 7	0.05–4.9 (2.5)	1.5–59 (25.3)	0.4–3 (1.3)	0.6–8 (3.4)	0.06–0.4 (0.2)	0.2–1.6 (0.9)	Low
4	FD ETA	GW = 0 S = 4	N/A	25–760 (297.8)	N/A	0.8–63 (26.1)	N/A	0.3–7.7 (3.3)	High
5	KC-135 Accident Area	GW = 1 S = 0	29	N/A	3.5 (3.5)	N/A	1.9 (1.9)	N/A	High
6	Hangar 253	GW = 4 S = 7	0.005–0.2 (0.1)	ND–6.5 (1.3)	0.04–0.2 (0.1)	ND	0.01–0.04 (0.03)	ND–1 (0.4)	Trace
7	Hangar 254	GW = 1 S = 4	0.03	ND–0.6 (0.3)	0.05 (0.05)	ND	0.02 (0.02)	ND–0.1 (0.03)	Trace
8	Tank Farm	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
9	Golf Course Maintenance Area	GW = 2 S = 0	0.008 (0.008)	N/A	0.005–0.006 (0.005)	N/A	ND	N/A	Trace
10	Firing Range Area	GW = 3 S = 6	0.4–11 (7.1)	1.1–1,500 (586.9)	0.29–2.4 (1.7)	ND–58 (29)	0.04–0.2 (0.1)	ND–8.3 (3.2)	High
11	Supply Building 122	GW = 13 S = 8	0.004–0.5 (0.2)	ND–0.7 (0.3)	ND–0.5 (0.2)	ND	ND–0.6 (0.1)	ND–0.5 (0.2)	Trace
12	Pease International Tradeport WWTF	GW = 2 S = 0	0.01–0.02 (0.02)	N/A	0.013–0.02 (0.02)	N/A	0.03–0.05 (0.04)	N/A	Trace
13	Pease International Tradeport WWTF Outfall	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
14	Flight Line Storm Sewer	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown

Table 3. Summary of Results from PFAS Source Area Assessment: Average Range of PFAS found in Groundwater (GW) and Soil (S)

Map No.	Source Area Name	Number of Samples	PFOS		PFHxS		PFOA		Contamination Level Category
			Groundwater (µg/L)	Soil (µg/kg)	Groundwater (µg/L)	Soil (µg/kg)	Groundwater (µg/L)	Soil (µg/kg)	
	System and other Drainages								
15	Flight Line Storm Sewer Outfall	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
16	Current Crash Fire Station	GW = 3 S = 2	0.1–1.3 (0.6)	46–120 (83)	0.04–0.7 (0.4)	1–6 (3.5)	0.01–0.2 (0.08)	0.6–3 (1.8)	Trace
17	IRP Site AT008 Recharge Trenches	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
18	Zone 3 Recharge Trench	GW = 4 S = 0	ND–0.1 (0.03)	N/A	0.01–0.02 (0.01)	N/A	ND–0.007 (0.003)	N/A	Trace
19	Golf Course Irrigation System	GW = 10 S = 6	ND–0.02 (0.006)	ND–2.8 (0.5)	ND–0.1 (0.03)	ND–0.5 (0.1)	ND–0.03 (0.008)	ND–0.6 (0.1)	Trace
20	Hodgson Brook	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
21	Haven Well Treatment Plant Area	GW = 80 S = 6	ND–0.2 (0.01)	ND	ND–0.2 (0.03)	ND–0.2 (0.1)	ND–0.08 (0.009)	ND	Trace
22	Sites 22 and 37	GW = 2 S = 0	ND	N/A	0.007–0.01 (0.009)	N/A	ND–0.01 (0.006)	N/A	Trace
23	Onsite landfills	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
24	Parking apron refuel area	GW = 0 S = 0	N/A	N/A	N/A	N/A	N/A	N/A	Unknown

GW = Groundwater; S = Soil.

Table 4. Soil and Groundwater Concentration Thresholds for Contamination-Level Categories

Category	PFOS, PFOA, or PFHxS soil (µg/kg)	PFOS, PFOA, or PFHxS groundwater (µg/L)
High	> 100	> 3
Low	> 10–100	> 1–3

6.2.2 Initial Groundwater Transport Review

For the 16 remaining source areas, we evaluated groundwater flow at the site to identify potential pathways to public supply wells. For our initial assessment of groundwater flow, we used a composite capture zone for the public supply wells that Amec Foster Wheeler (2017a) developed as part of a basewide investigation on PFAS contamination at the site. Based on this capture zone, we identified seven additional source areas that are unlikely to be sources of contamination to the water supply wells, due to lack of a groundwater pathway. These seven source areas include the Tank Farm (also referred to as the Bulk Fuel Storage Area), the Pease International Tradeport WWTF and WWTF Outfall, the Flight Line Storm Sewer Outfall (specifically the outfall and not the storm sewer itself, which is discussed further below), Hodgson Brook, the IRP Site 8 Recharge Trench, and onsite landfills.

In addition, we removed Sites 22 and 37 from further consideration in the historical reconstruction. While not completely outside of the capture zone, previous investigations suggest groundwater flow in this area moves away from public supply wells. The two sites demonstrated low-level contamination, and only a single well had PFOA concentrations above trace levels (**Table 3**), indicating that these sites were unlikely to be a significant source of PFAS contamination to public supply wells.

For the Haven Well Treatment Plant Area, concentrations are low relative to other source areas at the Pease site, and are only expected to cause low-level contamination to the Harrison well. While we have accounted for this low-level contamination in our analysis, it is not considered a significant source of PFAS to the rest of the public supply wells.

6.2.3 Timeline of AFFF-Related Activities

We then examined the timeline of known extent of AFFF use to assess the likelihood that the remaining areas were sources of contamination to the water supply wells. We found that the Firing Range, while highly contaminated, was likely not a potential PFAS source during the target timeframe of the historical reconstruction.

According to base personnel interviews, the NHANG FD released an unknown quantity of AFFF north of the firing range in 2006 (Amec Foster Wheeler, 2015). Abt found no additional details

on the nature of the 2016 release, and no other releases were reported for this area. Soil samples collected from this area had some of the highest PFOS concentrations found base-wide (**Table 3**), suggesting a significant volume of AFFF was released at this site. However, the Firing Range is located in the northern part of the site, east of the flight line along the southern edge of North Apron (Figure 6.1), over a mile from the nearest public supply well. Based on simple MODPATH estimates made by Amec Foster Wheeler (2016b), groundwater required approximately 4–5 years to travel a mile in the southern part of the site.

Assuming transport from the Firing Range to the Haven well takes at a minimum a similar amount of time, PFAS contamination related to a 2006 release would just be reaching the Haven well by 2013. Furthermore, the northern end of the Firing Range is at the edge of USAF's modeled public supply well capture zone, suggesting that only a portion of the PFAS contamination at the source would likely travel toward public supply wells. Ultimately, we concluded that the Firing Range was unlikely a significant source of PFAS to the public supply wells within our target timeframe.

6.3 Evaluation of Key Source Areas Contributing to Contamination

Ultimately, we identified six key source areas as potentially significant sources of PFAS to public supply wells during our target timeframe for the historical reconstruction (**Table 2**), including:

- Site 8
- Former Crash Fire Station
- KC-135
- FD ETA
- North Apron
- Flight Line Storm Sewer System

For each of these key source areas, we conducted a more in-depth review of the source area history, the PFAS chemistry, and groundwater transport information to qualitatively assess groundwater flow and potential transport of contaminants from the source area to public supply wells and to determine if a quantitative approach to simulate PFAS transport from the source area to the wells was possible. This additional in-depth assessment of each key source area is described in more detail below.

6.3.1 Site 8

Site 8 is located on the northern end of the runway at the Pease site. From 1961–1988, it was an active FD training site. In 1970 or 1974, USAF transitioned from using protein foam during fire training exercises to using PFAS-containing AFFF, including AFFF containing PFOS and PFOA. Trainings reportedly used between 200 to 1,500 gal. of JP-4 jet fuel. For a single training, a burn area would be saturated with water, and then the fuel would be poured onto a mock aircraft or

engine. Once lit, the fire would be allowed to burn for 1–2 minutes, and then extinguished using AFFF (CH2M Hill, 1984; Amec Foster Wheeler, 2017b).

Although the amount of AFFF typically used by USAF at the Pease site during their fire training events is not readily available, estimates from a study of training events at the Naval Air Station Fallon report concentrates of approximately 75–100 L of AFFF (Moody and Field 1999). These are assumed to be similar in size and scope to exercises conducted at Pease.

Furthermore, training exercises at Pease were reportedly conducted about twice monthly, which were "curtailed" in the winter months due to cold weather (CH2M Hill, 1984). Based on these estimates, approximately 475–630 gal. of AFFF concentrate may have been released at Site 8 annually. Assuming training exercises occurred for at least 14 years at the site (1974–1988), a total of approximately 6,600–8,800 gal. of AFFF concentrate, or 200,000–300,000 gal. of AFFF finished foam, would have been released at this source area. These estimates of total volume released are reliant on release estimates that are not site-specific, with very few additional reports to verify these values. Consequently, the total volume of AFFF released at Site 8 is a source of uncertainty. Furthermore, while literature suggests that 3M Lightwater was the most common AFFF used by the U.S. military when Site 8 was operational, PFAS concentrations measured in groundwater suggest other formulations were released at this site. In particular, groundwater samples at the eastern side of the source area show elevated concentrations of PFOA relative to PFOS than expected based on the formulation of Lightwater, presenting another source of uncertainty.

Site 8 contained two designated burn areas used for training purposes. The smaller burn area, located on the western side of Site 8, was used to simulate engine fires; and the larger burn area, on the eastern side, was used to simulate large aircraft fires. While recent aerial images from Site 8 show the burn areas are currently paved, historical images show the area was unpaved, bare ground during the time fire training exercises occurred at the site. During training sessions in these burn areas, some of the sprayed AFFF would have infiltrated into the unconsolidated overburden soils at the site. For the larger burn area to the east, foam that did not permeate the ground was generally collected by an 8-in. pipe that flowed north into a drainage swale.

This drainage swale led into a ditch that flows east into Pickering Brook, which eventually flows into Little Bay via Flagstone Brook. Hence, much of the surface runoff from the larger burn area, and perhaps some from the smaller burn area, was directed northwest of the Pease site, in the opposite direction of the Pease water supply wells. This northward pathway is confirmed by elevated PFAS measured in soil, sediments, and groundwater along the drainage, the brooks, and farther north (Amec Foster Wheeler, 2017b).

The foam that infiltrated into the ground directly at Site 8 resulted in elevated PFAS soil concentrations in the unsaturated vadose zone. The PFAS then migrated downward through the vadose zone to the underlying groundwater, as evidenced by elevated PFAS groundwater concentrations underlying Site 8.

Site 8 is located at a topographic high, which also forms a groundwater divide, with groundwater to the north of the divide flowing north, and groundwater to the south flowing

south. Under recent hydrogeologic and pumping conditions, Site 8 lies just north of the groundwater divide, and much of the flow from Site 8 is to the north, toward Little Bay and away from the Pease water supply wells. This is indicated not only by the groundwater elevation patterns, but also by elevated concentrations of PFAS (and other contaminants) measured in groundwater to the north of Site 8. The highest groundwater concentrations are measured to the north of the site and are generally 10 times higher than concentrations measured to the south of the site (i.e., 10–30 µg/L vs. 1–3 µg/L). Further, a bedrock trough that underlies Site 8 is believed to form a preferential pathway for deeper groundwater at the site toward the north/northeast.

While less elevated than concentrations to the north of Site 8, PFAS is nevertheless detected in monitoring wells to the south of Site 8, indicating that some portion of groundwater flow from the Site 8 source areas is (or has been) to the south. This poses the question, by what means did Site 8 PFAS contamination get transported to the south of the current groundwater divide?

Part of the answer to this question may be that the location of the groundwater divide at Site 8 has likely changed over time. This may be due to changes in physical parameters such as precipitation, and changes in pumping rates at the Haven well. It is possible that the location of the groundwater divide was farther north in the past, due to higher pumping rates at the Haven well, which would have resulted in the transport of more PFAS contamination from Site 8 toward the water supply wells to the south.

Overland wind dispersion may have also transported PFAS south of Site 8 along the ground surface, where it then could have infiltrated into the vadose zone south of the groundwater divide and would have consequently been transported toward the water supply wells.

Given the uncertainties in the amount of PFAS released and in how much contamination from Site 8 traveled north vs. south over time, quantifying the amount of PFAS transported from Site 8 to the public supply wells with any level of certainty is extremely challenging within our current tools and project timeline. To assess Site 8's potential contribution to PFAS contamination, we conducted some simplified modeling, based on a plausible scenario using reasonable assumptions (see **Section 10.1**). These results must be interpreted with caution given the exploratory nature of the model.

6.3.2 Former Crash Fire Station

The Former Crash Fire Station is located on the flight line, along the east side of the parking apron, north of the Haven well (see Figure 6.1). According to the preliminary assessment (Amec Foster Wheeler, 2015), this station was in service from 1954 to 2006, and was used as an AFFF storage facility from 1974 until closure of the base in 1991. NHANG FD personnel reported that AFFF concentrate was transferred from storage containers to respective ARFF vehicles at this location, evidenced by the station's stall for washing trucks. They further described that any releases within the building would have been collected by the sewer system, which drains to the WWTF away from the public supply wells. However, any surface drainage outside the

building would have been collected by the storm water collection system along the flight line and routed to the storm water outfall at McIntyre Brook. This storm water system was designed to be leaky, and therefore AFFF could have leaked into the soil and underlying groundwater along sections of the sewer line above the water table. It is believed that a majority of the storm drains underlying the parking apron and the drain entering the 108-in. storm drain from the northeast are above the water table (USGS, 1982). For drains below the water table, such as the storm drain coming from the south, it is expected that groundwater would flow into the pipe rather than water leaking out of the pipe.

In addition, spills or releases outside of the station could have infiltrated into the ground and migrated through groundwater to the public supply wells. While interviews conducted by Amec Foster Wheeler (2015) and our research revealed no documented spills of AFFF, elevated concentrations of PFAS measured in soil and groundwater suggest a significant amount of AFFF was released to the ground at this source area. The timing and nature of this release are unknown, but the reported activities suggest three potential releases at this station.

Small spills of AFFF concentrate during transfer activities. AFFF concentrate is diluted to 3% to create the finished foam used for fire suppression, meaning that a release of only 3 gal. of AFFF concentrate is equivalent to a release of 100 gal. of AFFF. A spill of 3 gal. of AFFF concentrate would be approximately 1% of the volume being transferred, if filling an ARFF crash vehicle, which can hold up to 200–500 gal. of AFFF concentrate.

Leakage of AFFF concentrate from storage containers. Assuming the base stored twice the amount of AFFF concentrate used during the KC-135 fire, the station could have held at least 5,000 gal. of AFFF concentrate. Assuming approximately 25 gal. of concentrate were used per training exercise, the base would see a turnover of at least 900 gal. of AFFF concentrate per year. A leak equivalent to only a small percentage of these volumes could lead to significant contamination of the area.

Release of residual AFFF from ARFF vehicles during truck-washing activities, as well as release of PFAS-contaminated tap water used to wash the trucks. Although the most likely release to have occurred, the resulting PFAS contamination would be minimal compared to the first two release types, because it would have involved low levels of diluted foam. Therefore, while it might be a contributor to contamination, we do not believe it represents the main type of release that occurred at this source area.

Ultimately, the Former Crash Fire Station represents a potential source to the Pease water supply wells, with two potential pathways:

1. Infiltration into the ground at the site, and migration through the vadose zone, followed by transport in groundwater toward the wells.
2. Transport along the Flight Line Storm Sewer System, with subsequent leakage into the soil and migration down to groundwater, which could have occurred at any point where the line is positioned above the water table, including portions of the pipe that cross the flight line close to the Haven well.

These potential release scenarios, especially involving AFFF concentrate, could result in significant PFAS contamination that may have started shortly after the USAF switched to

fluorinated AFFF in 1974. While the PFAS chemistry data show significantly elevated PFAS concentrations in soils and groundwater collected near the Former Crash Fire Station, suggesting some release occurred at this site, there is currently no information on the timing and nature of the release. Given the lack of information on the quantity and timing of that release, our ability to quantify the amount of PFAS transported through the vadose zone and groundwater from this area is limited, and any results would have significant uncertainty. Therefore, we did not attempt to quantitatively model PFAS transport from the source area, instead we conducted some simplified modeling to explore a hypothetical scenario based on the best information available to assess the potential contribution of the source area to PFAS contamination at the Haven well (see **Section 10.3**).

6.3.3 KC-135

On January 11, 1990, the front of a Boeing KC-135 aircraft exploded during routine fuel cell maintenance at the Pease Air Force Base in Portsmouth, NH. KC-135s are primarily used to refuel military aircrafts in flight. Kory Skalecki, an assistant fire chief of the NH Air National Guard FD, was on duty during the KC-135 accident. Mr. Skalecki stated that the accident happened near "row four on the parking apron near hangar 251," and estimated that 90,000 gal. of combined AFFF and water were used to put out the fire (Amec Foster Wheeler, 2015).

Interpretation of accounts from witnesses of the KC-135 accident lead to the conclusion that the AFFF and water mixture could have spread through the following pathways:

1. Infiltration through the vadose zone at the accident site, and transport through the aquifer. Some runoff from the runway, parking apron, and flight line shop area could have entered into the ground through cracks in the apron concrete and in the drainage culvert below the runway directly at the site of the accident. The AFFF could have then infiltrated through the unsaturated zone and into underlying groundwater, where it could then migrate along groundwater flow paths to the water supply wells. AFFF runoff could possibly have also reached the more porous grass-covered space between the parking ramp and the runway adjacent to the accident site and traveled through the vadose zone down to the aquifer at this location as well (Amec Foster Wheeler, 2017b).
2. Flight Line Storm Sewer System to the MacIntyre outfall. Surface runoff of the AFFF and water mixture could have been collected by the Flight Line Storm Sewer System from the KC-135 accident site. The Flight Line Storm Sewer System runs parallel along the parking apron, and then turns southeast across the flight line near the Haven well where it eventually discharges at the McIntyre Brook outfall. During the fire, there were anecdotal reports of foam entering McIntyre Brook at the outfall, which is consistent with foam being transported along this pathway and discharged to surface water, and away from the water supply wells. However, as noted previously, the culverts and drains were by design leaky, and thus AFFF (and PFAS constituents) could have leaked into the soil and groundwater along sections of the storm water flight line that are positioned above the water table.

Despite several uncertainties, we feel there is sufficient information to model transport of PFAS contaminants from the KC-135 source area to the public supply wells (the first pathway discussed above). We do not, however, feel that the information available allows us to reliably model the second transport pathway through the storm water system. Our decision to model the vadose zone-groundwater transport pathway at KC-135 is not necessarily a reflection of the source area's importance, nor does it indicate that we feel it is the only source of PFAS to the public water wells, but a reflection of there being sufficient data and information available.

6.3.4 FD ETA and North Apron

The FD ETA and North Apron are located in the northern part of the Pease site, east of the flight line and parking apron (see **Figure 3**). Both areas were used by the NHANG FD for testing and calibration of ARFF vehicle equipment, representing areas where low-volume, long- term AFFF releases likely occurred. According to the Preliminary Assessment (Amec Foster Wheeler, 2015), the NHANG FD tested their equipment on the north apron following closure of Site 8 in 1988 and were using the FD ETA by 2014 when the interviews occurred. The exact timing of when the NHANG FD transitioned from using the North Apron to using the FD ETA was not clear. The PFAS chemistry data indicates significantly higher PFAS contamination at the FD ETA compared to the North Apron, suggesting that less-significant releases of AFFF occurred at the North Apron compared to the FD ETA.

With regard to groundwater flow, the FD ETA is at the outer edge of the capture zone modeled by Amec Foster Wheeler (2016b). This capture zone was modeled using hypothetical pumping rates at each of the wells that were generally higher than the actual pumping rates of these wells in the 1990s and 2000s. Empirically derived overburden groundwater contours for time periods developed when the Haven well and other public supply wells were pumping less show the groundwater divide south of the FD ETA, which suggests that much of the contamination from this source area likely moved north, away from the public supply wells. The groundwater chemistry data show that the PFAS groundwater contamination primarily extends to the northeast of the FD ETA toward the highway, with little evidence of significant groundwater contamination extending south or southwest of the source area, further supporting this conclusion. However, contamination from the firing range and the North Apron may be masking a smaller plume in this direction, and consequently contributing to PFAS contamination in the public supply wells. Ultimately, while there are elevated levels of PFAS in the groundwater at the FD ETA source area, current uncertainties in the quantity used and released as part of the activities at this area, as well as the timing of those releases, prevent quantification of PFAS transport from the area. We did, however, conduct some simplified modeling, based on a plausible scenario using reasonable assumptions, which allowed us to assess the potential timing of contaminant arrival at the Haven well, as well as the potential magnitude of the PFAS concentrations (see **Section 10.2**).

For the North Apron, groundwater contours from different hydrologic conditions suggest that groundwater under at least part of the source area flows toward the public supply wells.

Elevated concentrations of PFAS were observed in both soils and groundwater collected adjacent to the area. Compared to other source areas, the PFAS concentrations observed at the North Apron were relatively low; however, they are still an order of magnitude above the current health advisory level and pose a contamination risk to the public supply wells.

Current data gaps limit our ability to model contaminant transport from the area. In particular, it is unclear at this time how often equipment testing and/or calibration occurred, and how much AFFF was released during these activities. There is also no information on where these activities occurred. Furthermore, the timeline of when these activities moved to the FD ETA is unknown besides that they began after closure of Site 8 in 1988.

Ultimately, these data gaps create significant uncertainties in the quantity released at the source area. Given the lower concentrations observed at this source area, we would expect that if PFAS from the North Apron was contaminating the public supply wells, the relative contribution would be small compared to more-contaminated source areas such as KC-135 and the Former Crash Fire Station. In addition, given that AFFF-related activities started after 1988, we would expect the timing for the arrival of PFAS from this source area to be after the arrival of PFAS from these more-significant source areas, which are closer and have similar or earlier timelines for AFFF releases.

6.3.5 Flight Line Storm Sewer System

The Flight Line Storm Sewer System is a drainage system that underlies the parking apron and runway areas (see **Figure 3**). The pipes collect surface water runoff from along the parking apron, which drains toward the middle of the flight line on the west side near the Haven well. Two large drains, one from the northeast and another from the south, connect to a larger 108-in. pipe that drains to an outfall at McIntyre Brook. According to USGS (1982), the drainage system consists of a series of interconnected concrete pipes that lie between approximately 3 and 20 ft below the surface. These pipe joints were designed to be leaky, potentially allowing AFFF-contaminated storm water to leak out of the drainage system, where the pipes lie above the water table or groundwater to leak into the pipes at locations where they lie below the water table (USGS, 1982).

In their 1982 report, USGS claimed that major storm drains under the parking apron are above the water table. They found that the large drain entering the 108-in. drain from the northeast is above the water table, whereas the drain entering from the south is below the water table. For sections of the drainage system within the Haven well cone of depression, including the east end of the 108-in. drain and the large drain from the south, water levels can substantially fluctuate due to daily changes in pumping rates. These fluctuations can increase the interchange of groundwater and water in the drains (USGS, 1982).

As described above, activities at several locations on or along the parking apron (potentially) released AFFF concentrate, finished foam, or PFAS-contaminated water that would have been collected by the Flight Line Storm Sewer System. This may have included foam sprayed

prophylactically when planes were being fueled along the apron. The drainage system would then serve as a potential secondary PFAS source, contaminating underlying soils and groundwater at locations where PFAS-contaminated wastewater leaked out of the pipes such as from joints along the major drains under the parking apron, from the large northeast tributary drain, and from the east end of the 108-in. drain, near the Haven well.

This secondary source serves to more rapidly transport PFAS contamination from different primary source areas (including the Former Crash Fire Station and KC-135) to the Haven well. Unfortunately, uncertainties in releases from the primary sources and in how much and where PFAS contamination leaked from the drainage system, prevent us from quantifying the transport of potential PFAS contamination at this source area to the public supply wells.

7. Modeling Approach, Methods, and Assumptions

Through the process described in **Section 6**, we narrowed the list of potential PFAS sources to the Pease Water System to six key source areas. Based on our review of site information and data, we believe that two main pathways may have transported PFAS from these source areas to the water supply wells:

1. **Physical ground water transport.** Infiltration at the ground surface, followed by migration through the soil vadose zone to groundwater, and transport along groundwater pathways to the water supply wells.
2. **Storm sewer system transport.** Collection and transport along the Flight Line Storm Sewer System, with possible leakage into underlying soils and groundwater along the sewer line.

However, given the inability to model the storm sewer system explicitly due to limited information, we focused on modeling groundwater transport, and then qualitatively assessed the potential implications of transport along the sewer line on contaminant timing and levels at the water supply wells (see **Section 10.4**). Of the six source areas, the KC-135 accident has the most-/best-defined information about the release, including an exact date and a reasonable estimate of the amount released. For this reason, we focused our quantitative modeling on this source, and evaluated the potential contributions of other key source areas based on modeling of plausible scenarios (see **Section 10**).

7.1 Analytical Modeling Approach

Based on recommendations from the Expert Panel (Ritter et al., 2020), we used models to simulate the transport and migration of PFAS contaminants from PFAS source areas to the Pease public supply wells via infiltration through the vadose zone and groundwater transport.

To simulate the transport through each media, the outputs of one model served as the inputs to the next model.

Our general conceptual approach for contaminant transport modeling at the Pease site was as follows:

- **Release of AFFF to the ground.** At each PFAS source area, PFAS-containing AFFF was released to the ground, where it infiltrated into the vadose zone. The nature, timing, and quantity of this release were specific to the different source areas, but fell into one of the following categories:
  1. AFFF was released through use as a fire extinguisher, which occurred during training exercises, or actual fire events
  2. AFFF was accidentally spilled or leaked from AFFF storage areas
  3. AFFF was released during equipment testing and cleaning activities
  4. Following its release, AFFF was transported through (and possibly leaked from) drainage ditches, storm drains, and other drainage systems
- **Transport through the vadose zone to the groundwater.** Following release of AFFF to the ground surface, PFAS contaminants began to migrate through the vadose zone to the water table. PFAS migration through the vadose zone was simulated using a one-dimensional model (HYDRUS-1D). Once at the water table, PFAS concentrations mixed vertically in the groundwater aquifer. A vertical mixing calculation was used to estimate PFAS concentrations in the aquifer.
- **Transport in the groundwater.** PFAS were then transported through the groundwater to the public supply wells. A two-dimensional, advection-dispersion model (2D-ADE) was used to simulate PFAS migration via groundwater to the public water supply wells. For the purposes of this project, we focused our modeling efforts on transport to the Haven well only. The Harrison and Smith wells are directly downgradient of the Haven well. We assumed low, constant concentrations at these two wells, because, when operational, the Haven well intercepted PFAS that would have otherwise migrated past the well location.
- **Simple mixing in the water distribution system.** The Expert Panel indicated that the mass-balance simple mixing model previously developed by ATSDR as a part of their Health Consultation (ATSDR, 2019) would suffice for estimating concentrations in the water supply system, with some refinements to the pumping data for the three Pease water supply wells, and inclusion of booster volumes and concentrations (Ritter et al., 2020).

We applied this modeling approach to simulate PFAS concentrations in the water supply system resulting from the KC-135 event, via physical groundwater transport. We then evaluated how the other key PFAS source areas identified in **Section 6** may have influenced the PFAS concentration profile. Without sufficient information to quantify the amount of PFAS transported through the vadose zone and groundwater, we evaluated potential timing and magnitude of the contributions of these other source areas to PFAS concentrations in the Haven well (see **Section 10**).

8. Groundwater Model Verification

To verify our groundwater model, we used available PFAS data in the southern area of the site, referred to as the southern well field. As described in **Section 4.2**, the Haven well shut down in May 2014. Following the shutdown of the Haven well, PFAS concentrations began to increase in monitoring wells and in the Harrison well downgradient of the Haven well. These increasing concentrations have been attributed to the southward migration of a PFAS plume that began in 2014 when the plume was no longer being intercepted by pumping at the Haven well. To assess migration of this plume, USAF contractors conducted regular sampling from 2014 to the present to monitor for PFAS concentrations in the public water supply wells and monitoring wells within this southern well field. We used these data and the migration of the PFAS plume through the southern well field to help calibrate and verify our two-dimensional (2D) groundwater model. Our initial inputs for the model came from:

1. Direct measurements at the Pease site
2. Modeled outputs from previous investigations
3. Literature-based values

Our final values for model input parameters were determined following a manual calibration process where we adjusted certain initial inputs within a reasonable range.

9. Modeled PFAS in Haven Well from KC-135

We estimated PFAS concentrations in the Haven well resulting from the KC-135 accident via the groundwater transport pathway. Below we briefly review the KC-135 accident event and describe our parameterization process for determining model input values for the one-dimensional (1D) vadose zone transport model and the 2D groundwater transport model. We then present modeling results and an uncertainty analysis, based on reasonable ranges for model input parameters. In **Section 10**, we assess how less-well defined PFAS releases from other key source areas may influence these modeled results.

9.1 Site Description

The KC-135 source area is located on the northern part of the parking apron along the east side near Hangars 253 and 254 (see **Figure 3**). On January 11, 1990, a KC-135 aircraft undergoing routine fuel cell maintenance caught fire and exploded. An estimated 90,000 gal. of AFFF concentrate and water mixture were used to suppress the fire (Amec Foster Wheeler, 2015). It is believed that the majority of the AFFF mixture acted as runoff from the asphalt parking apron and was captured by the Flight Line Storm Sewer System. However, asphalt does have some permeability; previous investigations assigned the asphalt at the site a recharge of approximately 5% of precipitation (Weston, 1993; Amec Foster Wheeler, 2016b). Elevated PFAS was measured in groundwater samples collected from a monitoring well just west and downgradient of the KC-135 area, including a PFOS concentration of 29 µg/L and a PFOA concentration of 1.9 µg/L (Amec Foster Wheeler, 2017a). While additional source areas upgradient of KC-135 could also be contributing to PFAS contamination in groundwater at this location, groundwater concentrations suggest that some portion of the AFFF released during the KC-135 incident infiltrated into the soil and contaminated underlying groundwater.

Given that only 4–6% of the released AFFF is believed to have infiltrated the paved ground at the source area, this means approximately 95% of the 90,000 gal. were shunted to the Flight Line Storm Sewer System, not transported via the vadose zone and groundwater, and were therefore not included in our vadose and groundwater transport models.

PFAS concentration. For concentrations of PFOS, PFHxS, and PFOA in the AFFF, we took an average of the PFAS concentrations measured in 3M AFFF formulations from 1988 and 1989. 3M was the dominant supplier of MilSpec-rated AFFF to the U.S. military at the time (Darwin, 2004) and 3M formulations are the only AFFF with significant PFOS content, and PFOS was the dominant PFAS found in groundwater near the source area (Field, 2017).

As the incident was in 1990, we chose to use an average of the measured PFOS, PFHxS, and PFOA concentrations from 3M formulations manufactured in 1988 and 1989. While it is possible that earlier formulations were used during the KC-135 incident, PFAS concentrations in those earlier formulations are not available (see **Section 3**). Review of available 3M formulation information, which spans the timeframe from 1988 to 2003, shows that PFAS concentrations in AFFF do change over time.

Finally, we assumed the AFFF was diluted to 3% of the AFFF concentrate, since the USAF typically used equipment meant for Type 3 AFFF (Field, 2017). The resulting concentrations of PFOS, PFHxS, and PFOA in the AFFF finished foam were 390 mg/L, 46.5 mg/L, and 3.75 mg/L, respectively.

9.2 Uncertainty Analysis and PFOS Results

The vadose zone model provides estimates of time it takes for the PFAS to migrate through the vadose zone and the PFAS concentration at the top of the groundwater table. We conducted an

uncertainty analysis by varying key input parameters for the vadose zone model that did not have a single best-estimate value but instead had reasonable ranges of values. The analysis focused on PFOS. Varying the values of these key input parameters within their reasonable ranges affected:

1. the resulting length of time for PFOS to migrate through the vadose zone to the groundwater table, and
2. the maximum PFOS concentration exiting the vadose zone.

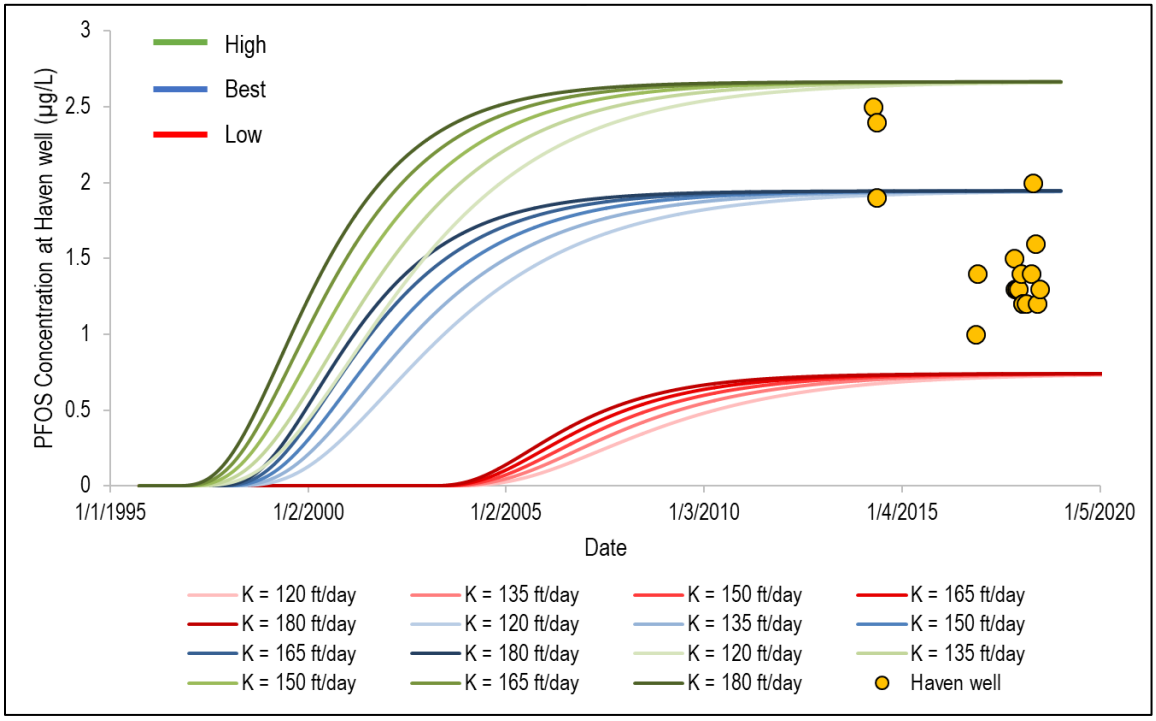
Based on this uncertainty analysis, three scenarios were developed – "low", "best", and "high". The "best" scenario used values for the key vadose zone model input parameters in the middle of their ranges.

Table 5 gives the results from the 2D Advection-dispersion equation (ADE) model for the low, best, and high scenarios, with the hydraulic conductivity value set to 180 ft./day, which is our best estimate. For these scenarios, the modeling indicates that PFOS reached a concentration of 0.07 µg/L at the Haven well in August 1997 (high), August 1998 (best), or June 2004 (low). This generally agrees with the measured PFOS data at the Haven well that has been relatively constant from 2014–2018. These results are in good agreement with the measured concentrations at the Haven well, which range from 1 to 2.5 µg/L PFOS in 2014–2018, compared to our modeled results that show maximum concentrations of 0.73, 1.94, and 2.66 µg/L PFOS for the low, best, and high scenarios, respectively (see **Figure 4**). We also see good agreement when we compare modeled PFOS concentrations to concentrations upgradient of the Haven well to measured PFOS concentrations from groundwater samples collected from monitoring wells along the transport path of the PFOS.

Table 5. 2D-ADE Groundwater Transport Model Outputs with K = 180 ft/day for Low, Best, and High Scenarios from the HYDRUS-1D Model

Scenario	PFOS source start date in groundwater for input to the 2D-ADE model	PFOS input concentration (µg/L)	Date to reach 0.070 (µg/L) PFOS at the Haven well	PFOS concentration at Haven well on May 1, 2014 (µg/L)
Low	1/8/2002	1.50	6/19/2004	0.73
Best	8/16/1996	3.93	8/9/1998	1.94
High	9/22/1995	5.39	8/2/1997	2.66

Figure 4. **Results of the 2D-ADE groundwater transport model uncertainty analysis for PFOS transport from KC-135 to the Haven well. [Note: Green colors are from our high estimate, blue from our best estimate, and red from our low estimate, based on HYDRUS-1D uncertainty analysis. The hydraulic conductivity value for each model run is shown in the legend.]**



9.3 Results for PFHxS and PFOA

To model PFHxS and PFOA from KC-135 to the Haven well, we applied the same vadose zone and groundwater aquifer inputs determined during the parameterization of PFOS. For source concentrations, we used the high, best, and low outputs from our vadose zone modeling; and ran them through the vertical groundwater mixing calculation to determine a constant concentration estimate for each scenario (**Table 6**). **Figure 5** presents the results from these model runs.

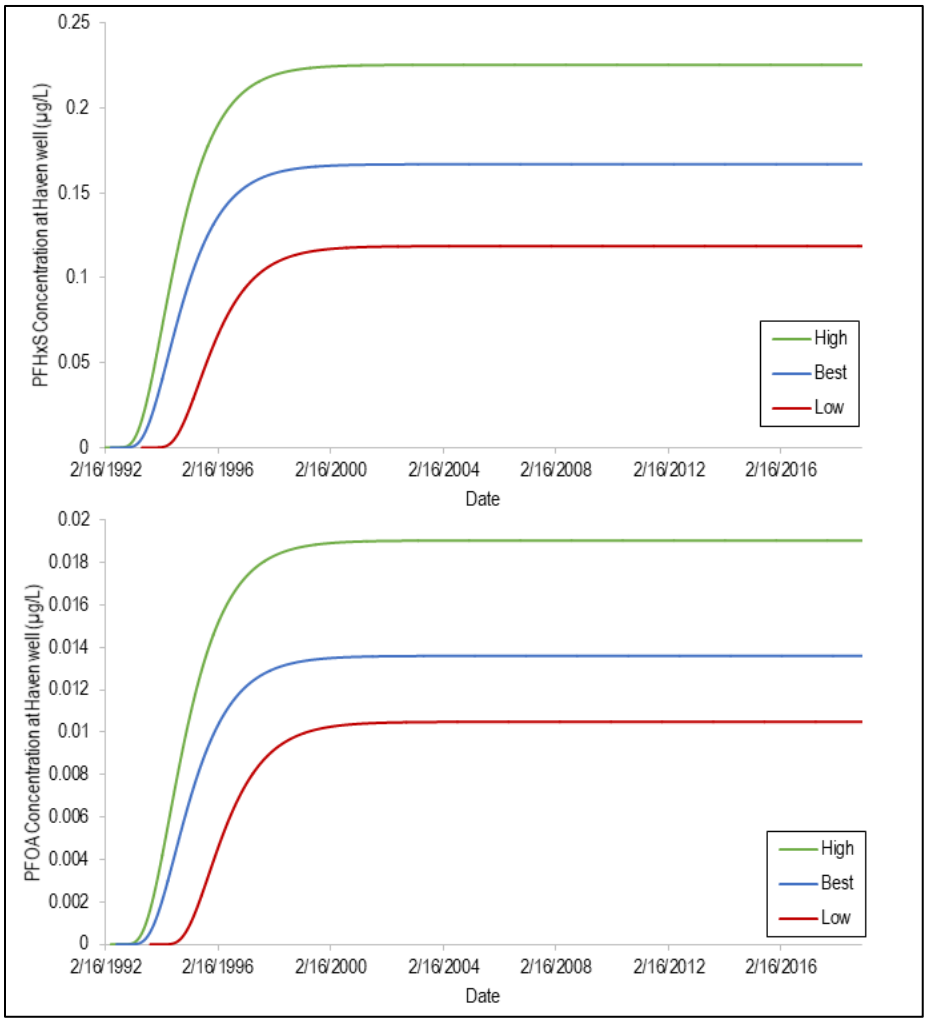
Table 6. **Initial Constant Source PFOS, PFHxS, and PFOA Concentrations from KC-135, and Modeled and Measured Concentrations at the Haven Well**

	PFOS Concentration µg/L Range (best estimate/average)	PFHxS Concentration µg/L Range (best estimate/average)	PFOA Concentration µg/L Range (best estimate/average)
Constant source concentration at KC-135	1.5–5.4 (3.9)	0.31–0.59 (0.44)	0.027–0.049 (0.035)
Modeled concentrations at the Haven well in 2018	0.74–2.66 (1.95)	0.12–0.22 (0.17)	0.010–0.019 (0.014)

Measured concentrations at the Haven well from 2014 to 2018	1.00–2.50 (1.51)	0.52–0.96 (0.73)	0.18–0.35 (0.26)

Overall, our modeled concentrations for both PFHxS and PFOA are considerably lower than the measured concentrations (**Table 6**). We believe this discrepancy is supporting evidence that other source areas are contributing to the Haven well contamination, particularly because PFHxS and PFOA have less retardation than PFOS, and therefore these PFAS can become enriched compared to PFOS when originating from more distal source areas such as Site 8, the North Apron, and the FD ETA. We explore this hypothesis further in **Section 10** when we evaluate potential contributions from these other source areas by modeling plausible scenarios.

Figure 5. Results of the 2D-ADE groundwater transport model for PFHxS and PFOA transport from KC-135 to the Haven well.



9.4 Summary

Our modeled PFOS concentrations in the groundwater reasonably match the measured PFOS concentrations from the Haven well in 2014–2018 (**Figure 4**). We also see reasonable agreement when we compare our modeled results at different distances upgradient of the Haven well to measured PFAS concentrations in monitoring wells at those same distances. Further, the relatively constant concentrations measured in the Haven well over this time period generally align with our modeled maximum concentrations, which is consistent with our conceptualization of a relatively continuous source from the KC-135 source area. The constant concentrations at the Haven well from 2014 – 2018 also constrains travel times, since PFOS seemingly reaches an asymptote at the Haven well by 2014.

While the overall range of predicted groundwater concentrations align with the variability in measured concentrations, it does appear our best estimate scenario slightly overestimates PFOS concentrations. This is especially true if KC-135 is not the only source contributing to PFAS contamination at the Haven well, which the PFOA and PFHxS modeling results suggest (see **Section 9.3**). One factor that may account for this overestimation is the additional retardation of PFOS due to the air-water interface, which we were unable to explicitly account for with our vadose zone model. Increasing retardation would result in later arrival times and lower PFOS concentrations in the Haven well than our models currently predict. Lower predicted concentrations would suggest other sources areas are contributing more significantly to the Haven well PFOS concentration profile.

While other source areas are likely contributors to PFAS contamination at the Haven well, our results suggest that release at KC-135 can account for much of the PFOS observed in the groundwater, even if additional retardation were incorporated. However, KC-135 may be a smaller contributor of PFHxS and PFOA. In **Section 6**, we identified other areas that are likely to be key sources of PFAS, but insufficient records on amounts of AFFF used and spilled over time, and in some cases the exact timing and nature of the releases, limited our ability to quantitatively model PFOS transport from them to the Haven well. For these source areas, we conducted simplified modeling for plausible scenarios that included several assumptions to address unknowns. Results of these models are provided in **Section 10**.

10. Assessment of Other PFAS Source Areas

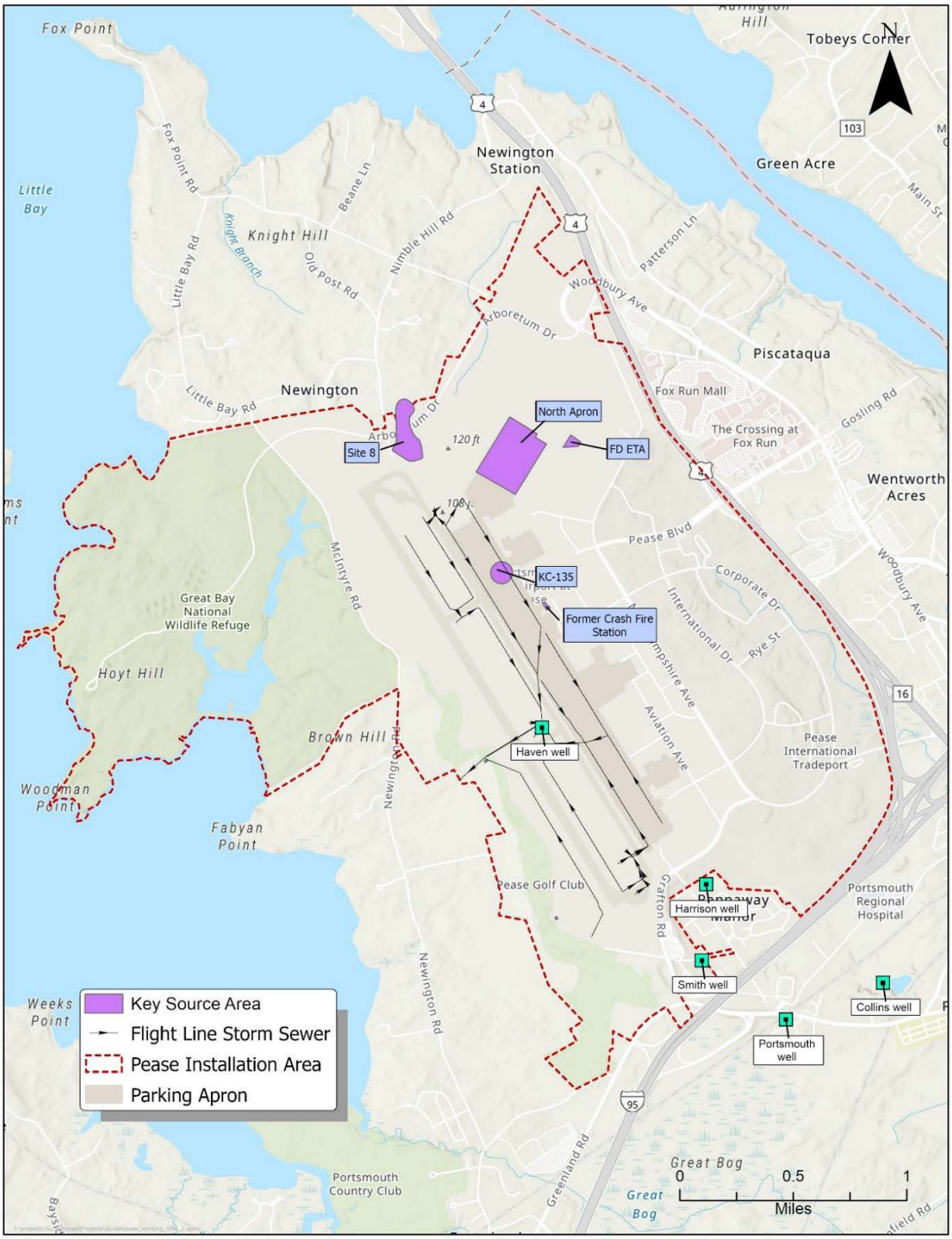
Besides KC-135, we identified five other key sources of PFAS at the site (as discussed in Section 6). Three of these source areas, Site 8, the North Apron, and the FD ETA, are located in the northern-most part of the site over a mile away from the Haven well. The other two source areas, the Former Crash Fire Station and the Flight Line Sewer System, are more centrally located along the parking apron closer to the Haven well (see **Figure 6**). The Flight Line Storm Sewer itself likely served as a rapid transport pathway and potential secondary source of PFAS

contamination related to all AFFF-related activities conducted along the flight line. Although data gaps and uncertainties in the amount and timing of the AFFF releases prevent full quantitative modeling of PFAS transport, in this section we provide a qualitative evaluation of PFAS contamination at and transport from the remaining key source areas. This includes conducting some simplified modeling, using plausible scenarios and reasonable assumptions. Results from our plausible scenarios and qualitative evaluation allows us to assess how the source areas may have contributed to PFAS contamination in the public supply wells.

For Site 8, the available information on North Apron, the FD ETA, and the Former Crash Fire Station allows us to make some bracketed estimates of PFAS arrival times and possible concentrations reaching the Haven well over time. Specifically, for each of these areas we have some information regarding the overall timing of the AFFF-related activities conducted at each area. However, our understanding of the amounts of AFFF released during those activities is less certain. To estimate the source PFAS concentration for input in the 2D-ADE (Advection-dispersion equation) groundwater transport model, we use measured PFAS concentration data from monitoring wells near and immediately downgradient of these source areas.

For the Flight Line Storm Sewer System and AFFF-related activities along the flight line, we do not have enough information to estimate a source concentration or influence on PFAS concentrations in the Haven well. However, we can evaluate PFAS transport and arrival times to the Haven well from these source areas using reasoned estimates for the timing of initial AFFF releases at the source area. A summary of these assessments is provided in **Section 10.1**.

Figure 6. Map Showing Six Key Source Areas.



10.1 Site 8

For the AFFF/PFAS releases, we assumed fire training events occurred two times monthly, and that approximately 100 L of AFFF concentrate were used per event. Since we do not have formulation information from AFFF prior to 1988, we used average concentrations from the 1988 and 1989 formulations across the entire time period starting in 1974 (which is the same inputs used to model transport from KC-135). Given that we do not know how much (or when) PFAS traveled north vs. south of Site 8, we mainly used HYDRUS-1D to determine the timing for PFAS contaminants to travel through the vadose zone to groundwater, but not the amount of PFAS reaching groundwater.

To model contaminant transport from Site 8 to the Haven well, we made the simplifying assumption that constant concentrations of PFOS, PFHxS, and PFOA transported south starting the year these analytes reached the water table until 2019, when we ended the model. The PFOS and PFOA concentrations we used were the average concentrations of those analytes measured in groundwater collected in 2013 from a monitoring well that lies a few hundred feet south of Site 8. Since PFHxS was not measured at this well, we used the concentration measured in a neighboring well slightly further downgradient. This sample was collected in November 2015.

Given AFFF releases at Site 8 ended in 1988, it is possible concentrations in the groundwater at Site 8 are declining, and therefore using concentrations measured in 2013/2015 as constant concentrations across the entire time Site 8 was operational could represent a low-end estimate. However, there are little data to verify this assumption or to support the use of other, potentially higher input concentrations.

Results from our modeled scenarios indicate that PFAS contamination at Site 8 moves through the ~ 25-ft. vadose zone quickly, reaching the water table within 2–3 years following the initial releases. This is a shorter timeframe for transport across the vadose zone than modeled at KC-135. This would mean PFOS contamination was in the groundwater at Site 8 by 1976 (if releases began in 1974), with PFHxS and PFOA reaching the water table slightly earlier. Therefore, to model contaminant transport through the groundwater from Site 8 to the Haven well, we began groundwater transport in 1976 and continued it through the end of 2018.

Based on our plausible scenario, we do expect Site 8 to contribute to the PFAS contamination at the Haven well during our target timeframe for the historical reconstruction. For PFOS, we estimate concentrations at the Haven well to have reached 0.07 µg/L in approximately 32 years, or by 2008, with Site 8-related PFOS concentrations reaching 0.19 µg/L by 2019. Note that these are estimated concentrations in groundwater at the Haven well, not the concentrations in the water supply system. Concentrations in the water supply system would be influenced by mixing with water pumped at the Smith well, which was also operational during this time period.

For PFHxS and PFOA, we estimate approximately 0.24 µg/L and 0.13 µg/L, respectively, reached the Haven well by 2019.

10.2FD ETA/North Apron

The North Apron and FD ETA source areas were used by the NHANG FD for testing and calibrating fire suppression equipment. These activities started after the closure of Site 8 in 1988 and were still ongoing at the FD ETA when NHANG personnel were interviewed in 2015 (Amec Foster Wheeler, 2015). According to these interviews, NHANG initially conducted activities at North Apron and then seemingly moved to FD ETA, although the timing of this transition is unclear.

For both these sources, there is little information on how much AFFF would have been released as a result of testing and calibration activities. This uncertainty, along with the uncertainty in when the NHANG FD transitioned from the North Apron to the FD ETA, as well as the uncertainty in variable groundwater flow paths prevent more quantitative modeling of PFAS transport. However, similar to Site 8, we were able to run some hypothetical scenarios, constrained by what information we do have about the timeline of AFFF use in these areas, to provide some insight into the potential timing and magnitude of these source areas' contribution to PFAS contamination in the public supply wells.

For our hypothetical scenario, we assumed all activities began at the FD ETA area in 1988. While we do not know when activities began at the FD ETA, PFAS concentrations in the soils and groundwater suggest testing activities occurred longer at the FD ETA than at the North Apron. Furthermore, the FD ETA is bare ground, as opposed to the North Apron, which is a paved surface, and therefore more of the AFFF released at the FD ETA would likely infiltrate the ground, and once infiltrated it would travel through the vadose zone more quickly than at the North Apron. Therefore, contamination from the FD ETA is more of a concern.

Similar to Site 8, the FD ETA sits at a groundwater divide with the dominant flow seemingly moving away from the public supply wells. Therefore, we only expect a portion of the total AFFF release to travel toward the public supply wells. Given the uncertainties in the amount of AFFF releases at these source areas, and subsequently how much transported toward the supply wells, we did not try to model vadose zone transport. Instead, we assumed that the travel time for PFOS to reach the water table would be similar to the travel time observed for Site 8 (i.e., ~ 2 years). We then assumed groundwater concentrations of PFOS (1.3 µg/L), PFHxS (0.55 µg/L), and PFOA (0.15 µg/L) have remained constant over time since reaching the groundwater table. These constant concentrations were based on measured concentrations in groundwater from a monitoring well located downgradient of both the North Apron and the FD ETA (toward the supply wells) during two sampling events in 2015.

Assuming PFOS contamination at the FD ETA travels through the vadose zone and reaches the water table in approximately 2 years following the initial release, we would expect the groundwater at these source areas to be contaminated with PFOS by 1990. By 2019, PFAS concentrations are just starting to arrive at the Haven well. Ultimately, based on this plausible scenario, the North Apron and the FD ETA do not appear to contribute significantly to PFAS concentrations in the Haven well during our target timeframe (i.e., 1993 to 2014).

10.3 Former Crash Fire Station

While there are no documented releases at the Former Crash Fire Station, PFAS concentrations in soil and groundwater samples collected from the area indicate that levels of contamination at the station are similar to levels observed under KC-135 and the FD ETA. Similar to Site 8, the North Apron, and the FD ETA source areas, the Former Crash Fire Station appears to be at a location where groundwater flow divides, with some of the flow continuing south/southeast along the parking apron and the remaining groundwater diverging east of the parking apron. Based on PFAS concentrations measured in the groundwater, it seems that again most of the groundwater flow (and PFAS contamination) moves eastward, away from the public supply wells, with only a portion continuing along the parking apron toward the Haven well.

With no information on timing of the releases, we can only assume a worst-case scenario would be that releases began in 1974 and continued to 2006 when the station was decommissioned. Assuming at least some of the releases occurred in grassy areas, we can expect PFAS contamination to reach the water table within 1–2 years, similar to Site 8 and the FD ETA. This increases to 5–7years if the contamination travels through and is under a paved area, similar to KC-135.

To estimate our constant source concentrations, we used PFAS concentrations measured in a monitoring well immediately downgradient of the station (0.96 µg/L PFOS, 0.15 µg/L PFOA, and 0.65 µg/L PFHxS). Ultimately, the results from our hypothetical scenario suggest PFOS concentrations could have reached 0.07 µg/L at the Haven well by the early 1980s via the groundwater transport pathway. And by 2019, up to 0.5 µg/L of PFOS may be reaching the Haven well from the Former Crash Fire Station. These results are predicated on the assumption that releases at this source area began in 1974 and were significant enough to result in µg/L-levels of PFOS in the groundwater by 1976. Given that this source area had no documented spills or releases and we had no explicit information regarding releases at the station, our assumption that releases began in 1974 was simply based on when AFFF-related activities began at the area.

10.4 Flight Line Storm Sewer System

Several of the source areas where AFFF-related activities occurred at the site sit along the flight line. Consequently, surface runoff from AFFF spills or releases at these source areas would generally be collected by the Flight Line Storm Sewer System. This sewer system runs north and south along the parking apron, connecting at the midpoint of the flight line near the Haven well. The sewer system then drains west past the Haven well area, and discharges into the McIntyre Brook. Once in the sewer system, AFFF or PFAS-contaminated storm water could be released into the ground from leaky joints along this flight line, thus contaminating the groundwater in the vicinity of the Haven well.

Earlier site investigations of a groundwater plume of trichloroethylene (TCE) with a suspected source along the flight line confirmed that the storm sewer is generally a pathway for

contaminants discharged along the flight line to the Haven well. Thus, while we cannot explicitly confirm that PFAS has been transported along this pathway, it is likely to have been the case. Any PFAS contamination that leaked out of the sewer system in the vicinity of the Haven well would likely get pulled into the Pease Water System via the Haven well almost immediately, given the shallow water table in this area.

While the full range of AFFF-related activities conducted along the flight line is currently unknown, we do know activities that could have resulted in the release of AFFF began in 1970/1974 (i.e., at the Former Crash Fire Station) and have continued to the present (i.e., at the Current Crash Fire Station). While a few larger releases have been reported during this timeframe (i.e., the KC-135 incident in 1990 and AFFF releases at Hangars 253 and 254 in 1992 and 1995), most of the activities conducted at these source areas would have resulted in low level, reoccurring releases of AFFF. These reoccurring activities could have been a source of relatively constant PFAS contamination to the Haven well during this entire time.

Collection of soil samples under the sewer line and analysis for PFAS could help to confirm this pathway, but as far as we are aware, no such data exist. However, PFAS that leaked from the sewer system decades ago may not necessarily be present in the soils today.

10.5 Summary

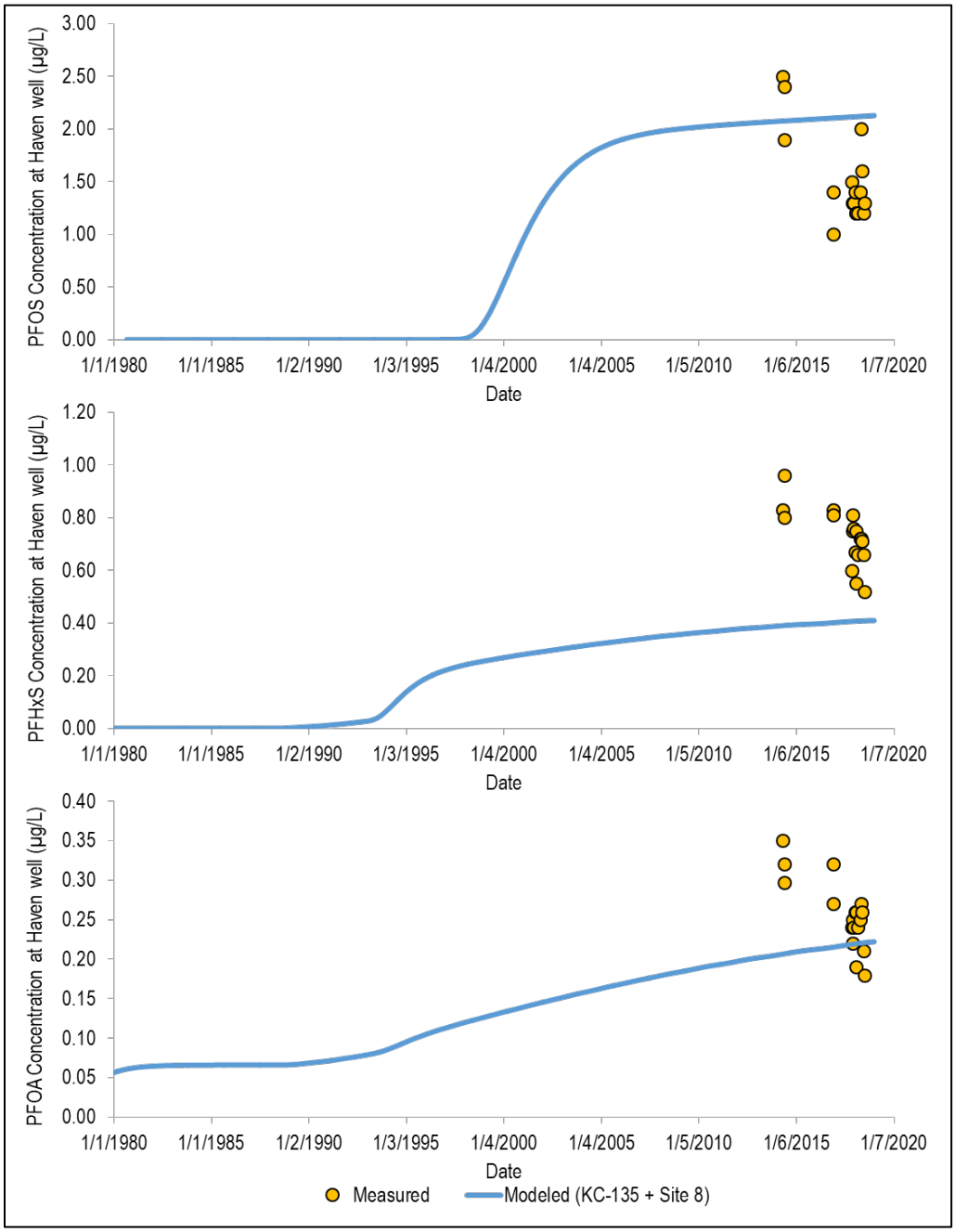
For four of our other key source areas (i.e., Site 8, North Apron, FD ETA, and the Former Crash Fire Station), we conducted simplified transport modeling using plausible scenarios and simplifying assumptions. Given uncertainties at these source areas, in particular with regard to quantities released and the changing direction of groundwater flow, we recognize certain assumptions we made have little data to support them, and therefore these results are not as quantitative as results from KC-135, which had better-defined inputs. However, we feel our results represent plausible scenarios that help to assess potential arrival times and the magnitude of PFAS contamination to the Haven well from these source areas.

Figure 7 shows concentrations over time for KC-135 and Site 8 combined. We focus on contributions from Site 8 because there is sufficient information to understand the nature and timing of the releases. Compared to the results from KC-135 only, we found that inclusion of Site 8 doesn't have a huge impact on the timing or magnitude of PFOS concentrations at the Haven well, although it does change the timing and magnitude of PFHxS and PFOA concentrations at the Haven well. In particular, the KC-135 incident and Site 8 were important to PFOS and PFOA levels in groundwater respectively. Based on our results, KC-135 appears to be the dominant source of the PFOS contamination, but does not explain PFOA levels, which appear to be largely originating from Site 8.

Our review of these six other source areas indicates that releases at one or more of these areas likely contributed to PFAS contamination at the Haven well during our target timeframe for the historical reconstruction. Moreover, our results suggest PFAS contamination could have reached the Haven well prior to the late 1990s, which is when we estimate contamination

arrived from KC-135; however, the uncertainty in timing of releases, specifically at the Former Crash Fire Station and from the Flight Line Storm Sewer System, makes it difficult to quantify the uncertainty in the estimated earlier arrival times for PFAS contamination to the Haven well. Finally, we found that including these additional source areas helped improve the discrepancies between our PFHxS and PFOA modeled results and measured concentrations, which we observed when we only included contamination from KC-135.

Figure 7. Summed estimated concentrations vs. time at the Haven well for PFOS, PFHxS, and PFOA originating from KC-135 and Site 8. Results are based on quantitative modeling for KC-135. For Site 8, estimated concentrations are based on simplified modeling of a plausible scenario from this source area.



11. Pease Water Distribution System Mixing Model Inputs and Findings

We used a flow-weighted, simple mass-balance mixing model similar to the model used by ATSDR for the Pease public health assessment (ATSDR, 2019) to estimate concentrations of PFAS contaminants in the Pease water distribution system due to the KC-135 incident. For this model, we applied average monthly water volumes from each of the inputs to the Pease water supply (i.e., the three Pease public supply wells and the boosted water from the Portsmouth Water Supply System) to modeled or estimated concentrations of PFAS contaminants to get a flow-weighted water concentration in the water distribution system. This model assumes water from each of the inputs is fully mixed before being distributed in the water supply system. The source of the water volume data, as well as our process for filling gaps in those data, are described in **Section 11.1**. Monthly PFAS concentration inputs for the mixing model vary by water supply source. To verify this simple mixing model, we used the model to estimate recent PFAS concentrations in the Pease Water System. We took measured PFAS concentrations in the Pease and Portsmouth supply wells and the reported pumped or boosted volumes from these water inputs to estimate PFAS concentrations in the Pease water distribution system. We compared these estimates to actual measured concentrations from several points along the water distribution system to assess accuracy.

11.1 Data Inputs

11.1.1 Well Pumping Data

To estimate past PFAS concentrations in the water supply system, we need information on the volume of water pumped to the distribution system from each of the water supply inputs, as well as the concentration in each of these inputs. For the supply wells, we obtained historical water supply system records from the City of Portsmouth. These records provided volumes of water pumped each month for the Pease and Portsmouth public supply wells from 1993 to 2018; however, a number of gaps in the data exist during this timeframe. Below we describe the gaps, and then our approach to filling them with estimated values.

11.1.2 Gaps in Monthly Pumping Records

Monthly pumping records for the three wells are available from the City of Portsmouth beginning in 1993. There were some temporal gaps in the records, which we were able to partially fill with information provided by the USAF. The remaining temporal gaps are presented in **Table 7**.

Table 7. Remaining Temporal Gaps in Monthly Pumping Records of Pease and Portsmouth Public Supply Wells

Haven Well	Smith Well	Harrison Well
• January–March 1993 • October 1994 • August–December 1996 • January–April 1998 • May–December 2000 • November 2001–March 2002	• January–March 1993 • March 1996 • August–December 1996 • January 1998–January 2003 • February–May 2019	• February–May 2019

For the temporal gaps, pumping rates needed to be estimated. To deal with these data gaps, for each month, we used the mean measured volumes within ± 2 years as the estimated monthly pumping rate at each well. These average monthly volumes were then used in instances when no pumping data were available.

11.1.3 Well Pumping Data Trends

The amount each public supply well contributed to the total water supply in the Pease system changed over time. To understand these changes, below we provide a summary of general trends observed in the monthly well pumping data during different periods of time:

1993–1997: Pumping rates at the Haven and Smith wells appear to alternate seasonally (the Harrison well was not active during this time). Approximately 66–100% of the water originated from the Haven well in winter and spring months, with the opposite in summer and fall months.

1998–2002: Annual data are available for both the Haven and Smith wells (the Harrison well was not operational during this time). Annual amounts indicate that the Haven well accounted for just over 50% of the supplied water in 1998 and 1999, and the majority of supplied water in 2000 and 2001.

2003–2005: During 2003–2005, the Smith and Haven wells pumped near-equal amounts, with the Haven well supplying slightly more than half of the total water supply.

2006–2010: The Harrison well was retrofitted and began operations in May 2006. Once in operation, the new Harrison well supplied approximately 38% of the total water from 2006 to

2010. The Smith well was not operational from July 2006 through November 2007, but normal operations were resumed after that period. The Haven well was shut down for maintenance from November 2007 to January 2008.

2011–2013: In 2011, an upgrade to the regional water management system allowed for boosted water volumes to be recorded. From 2011 to 2013, City of Portsmouth staff estimated that the Portsmouth booster accounted for approximately 17.5% of the total volume pumped in the Pease Water System. This percentage is an overall average and does not account for potential temporal variations.

2014–2018: The Haven well was shut down in May 2014. Since the closure of the Haven well, the proportion of Booster water was increased from ~ 17.5% to ~ 37%.

11.1.4 Boosted Water

In addition to the three groundwater wells, the Pease Water System also received water via a booster. The booster was installed in the mid-1990s, but the total amount boosted from Portsmouth was not recorded until 2011. The total water supply in the Pease system was not recorded, only the pumping rates at the individual wells. The lack of information on the amount of boosted water prior to 2011 creates challenges in modeling, as it effectively introduces an undefined dilution factor over periods of time when the booster was operated (these time periods are also not recorded). However, pieces of anecdotal information learned from City of Portsmouth staff help to constrain this unknown to a certain extent:

- The booster was only operated periodically, and only the minimum amount needed to supplement or meet demand was boosted.
- When in operation, the boosted water was always less than 50% of the total water supply.
- For the time period after records of boosted water are available and prior to the Haven well shut down (i.e., 2011–2014), boosted water accounted for approximately 17.5% of the total water supply (Rice and Goetz, 2015).

For purposes of the historical reconstruction, we evaluated two scenarios, varying the amount of water boosted from Portsmouth from 0%–17.5% over the full modeled time period.

Major Gaps in Pease Water System Mixing Model Pumping Inputs

- Temporal gaps in City of Portsmouth monthly pumping records
- Lack of information on the amount of boosted water prior to 2011 in the Pease Water System

11.2 Estimated Drinking Water Concentrations Related to KC-135

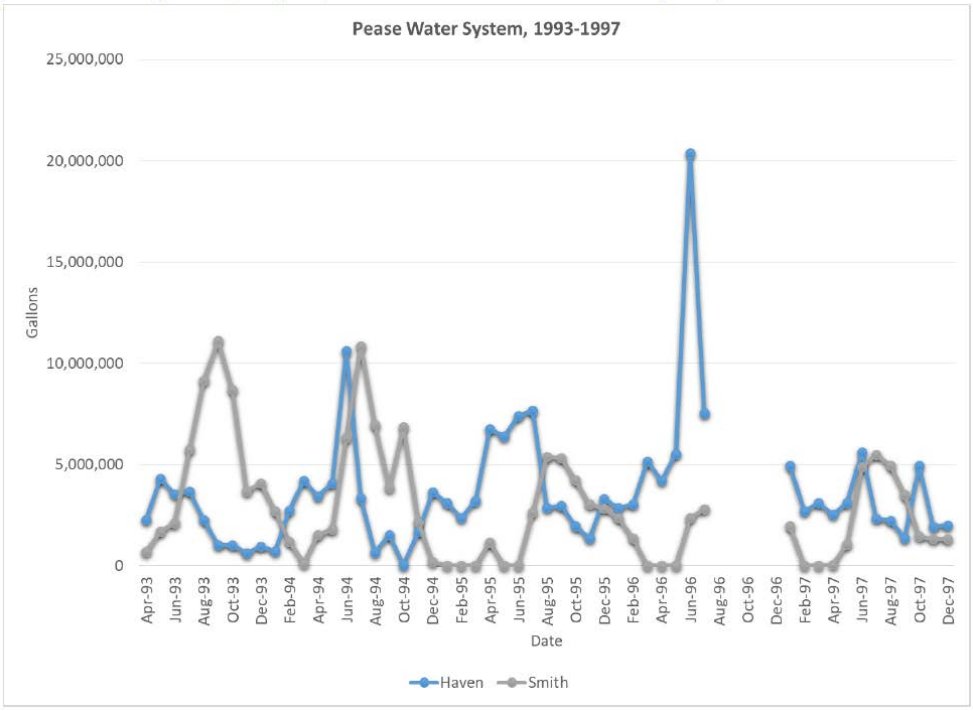
The estimated PFAS concentrations for the Harrison well, Smith well and boosted Portsmouth water used in the water supply system mixing model are shown. Assuming 17.5% of the total

water supply was boosted from the Portsmouth Water Supply System, the mixing model results indicate that PFOS concentrations in the Pease Water System would have reached the NH state standard of 0.015 µg/L PFOS by March 1998, the EPA advisory level of 0.07 µg/L PFOS by November 1998, and become elevated above 1 µg/L PFOS by December 2012, based on the best estimate scenario.

For the high scenario, this shifts to April 1997 and October 1997 to reach 0.015 µg/L and 0.07 µg/L PFOS, respectively (approximately a year earlier), and it becomes elevated above 1 µg/L by May 2001 (over 10 years earlier). For the low scenario, PFOS concentrations do not reach 0.015 µg/L until December 2003 or 0.07 µg/L until February 2005, and concentrations never get above 0.5 µg/L.

If we assume no boosted water, PFOS concentrations reach 0.07 µg/L earlier for all three scenarios than when 17.5% boosted water is assumed (December 2004, October 1998, and October 1997 for the low, best, and high scenarios, respectively). Likewise, PFOS concentrations become elevated above 1 µg/L earlier (April 2002 and April 2000 for the best and high scenarios, respectively; the low scenario never gets above 0.5 µg/L). Overall, for the 0% boosted water scenarios, we see an increase in concentrations by approximately 20% compared to our 17.5% booster water scenarios. This is not surprising given the estimated PFOS concentrations in the boosted water are considerably lower than concentrations in the three Pease supply wells.

Figure 8. Total gallons pumped per month into the Pease Water System, 2003 – 2005.



Our results found a strong influence of Haven well pumping rates on PFAS concentration in the Pease water system, showing a steep decline and then increase in concentrations while the Haven well was closed for maintenance.

For PFHxS and PFOA, drinking water estimates are significantly lower than estimated in ATSDR's 2019 Health Consultation (ATSDR, 2019), a reflection of the discrepancy between the measured and modeled concentrations at the Haven well (see **Section 9.3**). This discrepancy is evidence that other source areas are contributing to the contamination in the Haven well, in addition to KC-135, particularly because PFHxS and PFOA experience less retardation than PFOS, and hence could contribute a comparatively higher proportion of the total PFAS originating from more distal source areas over the relevant timeframe. Site 8 specifically demonstrates a different PFAS signature, with higher PFOA concentrations, which may account for a large portion of the PFOA observed in the Haven well. Unfortunately, insufficient information prevented more rigorous modeling of these other source areas; however, we explored hypothetical scenarios that allowed us to assess our above hypotheses.

Ultimately, the modeled results suggest that AFFF used during the KC-135 incident would have resulted in PFOS concentrations above the EPA advisory level in the Pease water system within ~ 7–8 years, or very shortly after it reached 0.07 µg/L in the Haven well. The state's standard of 0.015 µg/L would have been reached a few months earlier. These estimates do not take into account other sources areas, which likely also contributed to the PFAS contamination at the Haven well. In this respect, the estimated concentrations may be a minimum estimate of PFAS concentration in the Pease Water System over time, with PFOS concentrations in the water system reaching advisory levels earlier. Our modeling also does not take into account the potential for rapid transport along the Flight Line Storm Sewer System to the Haven well.

11.3 Estimated Drinking Water Concentration from Combined Key Source Area Contributions

To assess the potential influence of Site 8 on PFOS, PFHxS, and PFOA drinking water estimates, the estimated concentrations at the Haven well over time from KC-135 and Site 8 were summed get overall concentrations over time at the Haven well. For North Apron and the FD ETA, model results suggest PFAS contamination would just be arriving at the Haven well by 2014 (the end of our target timeframe), and therefore they are not expected to contribute significantly to our drinking water estimates. **Figure 9** shows the estimated drinking water concentrations for PFOS, PFHxS, and PFOA, assuming 17.5% booster water volumes. Given that we do not have estimated uncertainty for Site 8, we only present estimated drinking water concentrations for a best estimate scenario.

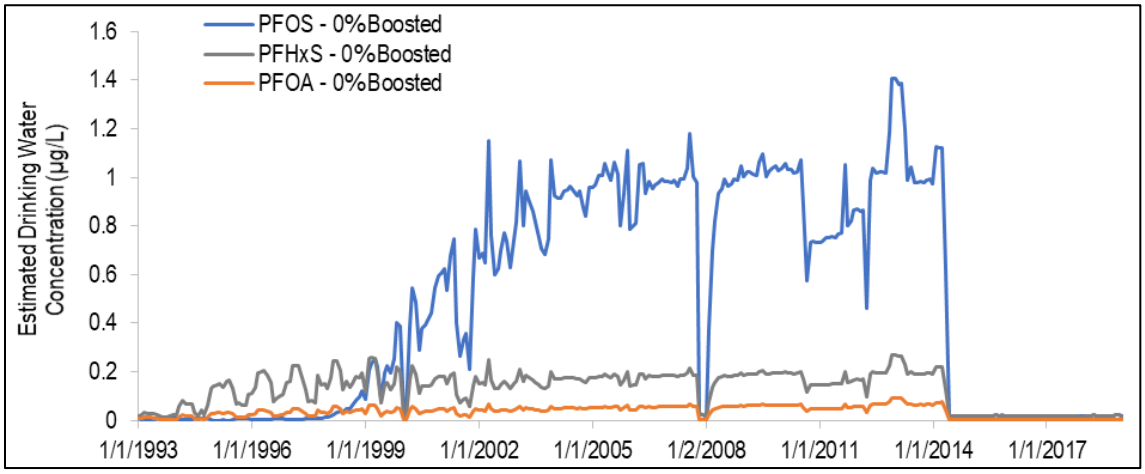
When we include Site 8, we find that PFHxS and PFOA estimated drinking water concentrations increase but there is minimal change to the PFOS concentrations over time at the Haven well, with PFOS contamination from Site 8 arriving after PFOS contamination from KC-135 and at considerably lower concentrations.

For PFHxS, concentrations reach the NH state standard of 0.018 µg/L by February 1993 and 0.07 µg/L by December 1994 for the 17.5% boosted water scenario. The maximum PFHxS concentration for this scenario is approximately 0.25 µg/L.

For PFOA, concentrations reach the NH state standard of 0.012 µg/L by February 1994, but do not reach the EPA health advisory level of 0.07 µg/L until December 2012 for the 17.5% boosted water scenario.

These results show the potential importance of the other source areas, such as Site 8, to historical estimates of drinking water concentrations. However, as noted above in **Section 10**, there are many uncertainties and assumptions that went into our attempt to model PFAS concentrations from these sources, which reduces confidence in the results. Therefore, we recommend future work attempt to address uncertainties associated with AFFF releases to improve these estimates. Though we recognize that considerable effort has already been made to compile historical site information, and it may be challenging to completely verify the timing and amounts of AFFF releases, given limited site records.

Figure 9. Estimated drinking water concentrations for PFOS, PFHxS, and PFOA, assuming 17.5% booster water volume. PFAS concentrations in the Haven well are based on the modeled contribution from Site 8 and the KC-135 incident.



12. Summary and Recommendations

A historical reconstruction of PFAS concentrations in the Pease Water System was conducted to estimate PFAS concentrations in the water supply system at the Pease International Tradeport from when it opened in 1993 to when we first have measured PFAS data at the supply wells in 2014. For this effort, PFAS concentrations at the three public supply wells – the Haven,

Harrison, and Smith wells, were modeled or estimated. A simple mixing model was applied to these concentrations over time, combined with well pumping rates, to estimate PFAS concentrations in the Pease Water System over time. Below is a summary the key findings from this work.

12.1 Key Findings

12.1.1 AFFF Formulations

Review of AFFF formulations and history of AFFF use by the U.S. military demonstrated that the dominant brand of AFFF used at U.S. military installations from the 1970s–early 2000s was 3M Lightwater, predominantly consisting PFOS, PFHxS, other PFSAs, and PFSA precursors. Reports indicated that the USAF primarily used equipment for Type 3 AFFF, which dilutes the AFFF concentrate to 3% in the finished foam. AFFF formulation data in the literature are sparse, with little information on formulations manufactured before the late 1980s, limiting our ability to fully account for earlier AFFF formulations in model inputs. Site chemistry data suggest different formulations may have been used, including a formulation with higher PFOA (or PFOA precursor) content.

12.1.2 PFAS Source Areas

A review of site information on AFFF use, handling, accidental release, and disposal identified 23 potential PFAS source areas at or near the Pease site. From these 23 areas, we identified six key PFAS source areas, which likely contributed to the PFAS contamination in the Pease public supply wells. Of these six areas, AFFF-related activities at KC-135 were the most defined and best characterized, including an exact date for the release and a reliable estimate of the amount released. Therefore, we focused our quantitative analysis on this area.

For the other five key source areas, data gaps and uncertainties in the amount and timing of the AFFF releases prevented full quantitative modeling of PFAS transport. For a number of these areas, modeling was further complicated by groundwater divides and complex transport pathways. Despite these uncertainties, plausible scenarios using simplifying assumptions were modeled to evaluate potential timing for the arrival of PFAS contaminants to the Haven well from each source. This allowed us to assess the potential magnitude of the contribution from these other source areas. We recognize the results from these model runs have significant uncertainties and therefore consider our analyses of these source areas to be more qualitative in nature.

When developing our conceptual site model, we noted that all six of our key PFAS source areas are upgradient of the Haven well, which is subsequently upgradient of both the Harrison and

Smith wells. The data suggest that when Haven well was operational, it effectively intercepted most of the PFAS contamination from these upgradient sources. Therefore, we mainly focused on the transport of PFAS contaminants from the six key source areas to the Haven well, and assumed a low-level constant concentration in the other two supply wells.

12.1.3 KC-135 PFAS Transport Model Results

Overall, we saw reasonable agreement when we compared our modeled results for the transport of PFOS from KC-135 to measured concentrations of PFOS at the Haven well, as well as at different distances upgradient of the Haven well. On the other hand, modeled concentrations for PFHxS and PFOA are considerably lower than measured concentrations. These discrepancies are reduced when we include contamination from other sources, specifically Site 8.

Based on our results, KC-135 appears to be a major source of PFAS to the Haven well, with our best estimate accounting for most the PFOS observed. However, given that our vadose zone transport model does not account for retardation related to the air-water interface in the vadose zone, our current best estimate may be over-estimating PFAS concentrations contributed solely by KC-135. If this is the case, other source areas may be contributing a larger percentage of the PFAS contamination to the Haven well.

12.1.4 Assessment of Other Key Source Areas

For the other key source areas (except the Flight Line Storm Sewer System), we conducted transport modeling using plausible scenarios and simplifying assumptions. Our results indicate these other source areas likely contributed to PFAS contamination at the Haven well before the late 1990s, which is when we estimate contamination arrived from KC-135. Comparing our modeled results from these other source areas (inclusive of KC-135), we found reasonable agreement between modeled and measured concentrations. Including Site 8, in particular, improved the discrepancies between our PFHxS and PFOA modeled results and measured concentrations, observed when only KC-135 contamination was included.

12.1.5 Flight Line Storm Sewer System

The Flight Line Storm Sewer System collects surface runoff from AFFF spills or releases at source areas along the flight line. Once in the sewer system, AFFF or PFAS-contaminated storm water could be released into the ground from leaky joints along this flight line and contaminate soils and the underlying aquifer in the immediate vicinity of the Haven well. Earlier site investigations of a TCE groundwater plume confirmed that the storm sewer is a pathway for

TCE contaminants discharged to the Haven well. We believe this study indicates that the Flight Line Storm Sewer System likely represented a rapid transport pathway and secondary source of PFAS contaminants to the Haven well. However, little data exist to confirm this, or to provide estimates of the magnitude of contamination potentially contributed by this pathway.

12.1.6 Estimated Drinking Water Concentrations

Based on contributions for KC-135 alone, results of the simple mixing model indicate that PFOS concentrations in the Pease Water System could have reached the NH state standard of 0.015 µg/L by 1997–1998 (followed by the EPA health advisory of 0.07 µg/L a few months later), with higher concentrations occurring throughout the 2000s. Modeled PFHxS and PFOA concentrations from KC-135 were generally lower than PFOS, although PFHxS did reach the NH state standard of 0.018 µg/L by 1994–1995. When we include contributions from Site 8, we found PFOS contamination was minimally impacted, but PFHxS concentrations reached 0.015 µg/L by early 1993 and 0.07 µg/L by 1994 and PFOA concentrations reached 0.012 µg/L by 1993 and 0.07 µg/L by 1994, similar to PFHxS.

12.2 Recommendations and Next Steps

Based on review of the data and our preliminary results, we recommend the following next steps:

- **Continue investigations into AFFF formulations.** Understanding concentrations of different PFAS in AFFF formulations helps improve release estimates, which is an important variable when estimating PFAS transport from areas contaminated with AFFF.
- **Enhance understanding of AFFF-related activities.** Additional information on how AFFF was released at different source areas and as a result of different activities can help bound estimates of release quantities at each source area. This information could be gathered through additional interviews with personnel who currently conduct or have conducted these different activities at military installations (e.g., fire training exercises, equipment calibration, transfer of AFFF to ARFF equipment).
- **Incorporate retardation due to the air-water interface into vadose zone modeling.** Adsorption at the air-water interface is an important component of PFAS transport through the vadose zone, and incorporating this factor into the vadose zone modeling may help explain why PFAS remain in the vadose zone for decades after releases to the ground surface cease.
- **Incorporate spatial and temporal variability of parameters.** As many model parameters vary with time and spatially across the site, a numerical model, such as MODFLOW can be used to better incorporate these variations.
- **Conduct additional groundwater sampling upgradient of the Haven well.** Additional sampling upgradient of the Haven well could provide valuable information to assess trends

in PFAS concentrations, verify results from single sampling events, and characterize additional areas at the site.

- **Conduct additional soil and groundwater sampling along the Flight Line Storm Sewer System.** Sampling the sewer line and underlying soils may help verify if PFAS have been transported along the Flight Line Storm Sewer System, and potentially provide data on the general magnitude of this pathway and sources of PFAS contamination in the Haven well.
- **Confirm modeled drinking water estimates using PFAS water-serum models.** Using available blood serum data from the community, the recently developed pharmacokinetic model, linking PFOS and PFOA concentrations in drinking water to blood serum levels, could provide important verification for the modeled drinking water estimates of this report.

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