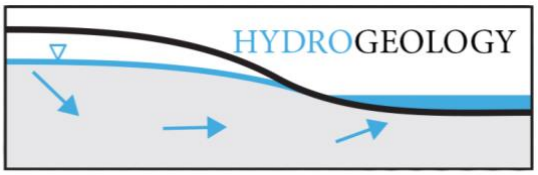
Report in support of Technical Documents Associated with PFCS Contamination at the Barnes Air National Guard Base, Westfield, Massachusetts



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1. Executive Summary

I have reviewed the documents associated with PFCS (Perfluorinated Compounds) contamination at the Barnes Air National Guard (ANG) Base including the 3 reports associated with the site investigation and the individual PFCS testing reports from the Massachusetts DEP. In summary, the reports document widespread contamination of PFCS across ground and surface waters in the southern Barnes aquifer adjacent to and on the Westfield-Barnes Regional airport, and two areas of localized soil contamination on and adjacent to the Barnes ANG Base. These areas are associated with base operations and fire fighting in response to an aircraft crash. While the soil contamination based on the expanded site inspection (ESI) report seems to be localized, the groundwater contamination is extensive. The aquifer conditions below the site are conducive to rapid migration of contaminants despite prior occurrences of limited mobilization of other contaminants. Downward gradients of flow in the aquifer are quite large and have led the plume to be distributed across all depths sampled in the 2020 ESI. Down gradient public water supply wells and homeowner wells have evidence of PFCS contamination consistent with the flow paths of groundwater on and through the site. Recommendations for further site investigations include a more comprehensive geophysical survey of the aquifer system, development of a conceptual site model, development of a quantitative groundwater flow and transport model, and drilling and sampling of the sedimentary bedrock aquifer, which is likely contaminated as well.

2. Introduction

Dr. Boutt was contracted to provide a technical assessment of the PFCS contamination in and around the Barnes ANG Base. The objectives were to 1) provide an independent review and technical support to the Barnes Restoration Advisory Board (RAB) with a document review and data interpretation of the current technical documents associated the Barnes Aquifer; 2) present the information to the RAB and the local community during a public presentation; and 3) participate in bi-monthly update calls with representatives of the RAB.

3. Scope of Review and Assessment

This report is a deliverable in support of contract #W50S8123P0005 for the Barnes RAB under a TAPP grant. The contract specified that Dr. Boutt would 1) summarize the information gained from the reports in regard to the plume(s) associated with the PFCS contamination; 2) assess the characteristics, size, migration, profile, fate, and transport of the plume(s) as it relates to the

municipal and private well water drinkers; and 3) provide context and the opportunity to help educate the RAB and community to better understand the technical documents completed at this time.

The following reports were analyzed:

- Final Perfluorinated Compounds Preliminary Assessment Site Visit Report (BB&E. 2016)
- MA DEP NOES & Private Well Sampling Results (2017- Present)
- Final Phase 1 Regional Site Inspection Report for Perfluorinated Compounds (AMEC. 2018)
- Final Expanded Site Inspection Report for PFCS (Parsons. 2020)

Additional documents were reviewed in support of the summary and are listed in the Appendix.

4. Groundwater and the Hydrogeology of The Barnes Aquifer System

a. Hydrogeology 101

The Westfield-Barnes Regional Airport and the Barnes ANG Base sit on top of a prolific aquifer system. Aquifers are subsurface water-bearing reservoirs that store and transmit water at economically significant levels. Water moves into aquifers (Figure 1) through the soil infiltration of precipitation. Water moves underground, often for distances of hundreds of miles, towards lower lying areas before eventually coming to the surface. There are two types of aquifers: unconfined aquifers, which are open to the atmosphere, allowing water to move vertically to recharge them; and confined aquifers, which are not directly open to the atmosphere, and so the vertical connection to the surface is limited. Unconfined aquifers are generally more susceptible to surface contamination sources. Contaminants in the soil can move vertically downward to the water table and then be transported horizontally for large distances.

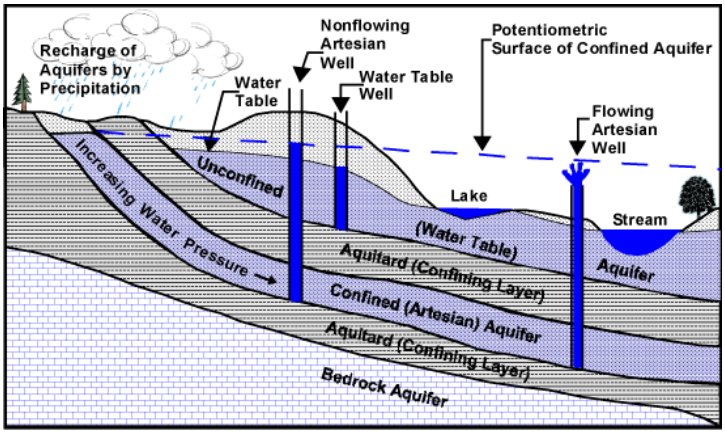

Figure 1 - Diagram depicting the groundwater processes and characteristics of confined and unconfined aquifers.

The transport of water through aquifers can be complex, and travel times (the time it takes for water to enter and leave the ground) can be lengthy (Figure 2). The transport of water and any contaminants can move through the aquifer towards sensitive receptors such as wells, lakes, or ponds. The aquifer system can take a localized source of contamination and widely disperse it.

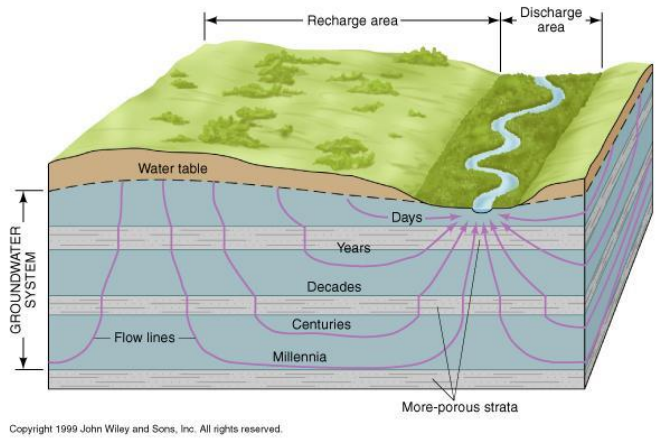

Figure 2 - Diagram depicting the timeframe of groundwater movement relative to the distance between a recharge area and a discharge area.

b. Glacial Geology and the Barnes Aquifer

Around 18,000 years ago, glaciers covered the region in a large ice sheet called the Laurentide Ice Sheet. As the climate warmed, the glaciers retreated and left behind sediments and water. The water on the surface accumulated in extensive pro-glacial lakes, such as the one which was situated in the Connecticut River valley, called Glacial Lake Hitchcock. Thick piles of sand and gravel which were deposited from streams entering the lake accumulated along the margins of the lake. These deposits, called deltas, can be up to 200-300 feet thick and are often flat on top. This topography makes them good places to place airports. The coarse-grained nature of the deposits makes it easy for water to infiltrate them. These deposits make good aquifers because of the high rate of water flow and often unconfined conditions, which create a higher water storage capacity. One such large delta deposit called the Barnes aquifer (yellow area in Figure 5) covers an area to the west of the Holyoke range (Figure 3) and the local region. The orange colors in Figure 3 map the distribution of sand and gravel deposits. The red box indicates the approximate study area in the Barnes ANG Base reports. A geologic cross section of the southern part of the Barnes aquifer (locally termed Pond Brook aquifer) is shown in Figure 4. Key aspects of this aquifer are that it is unconfined, composed of thick sand and gravel, and underlain by sedimentary bedrock.

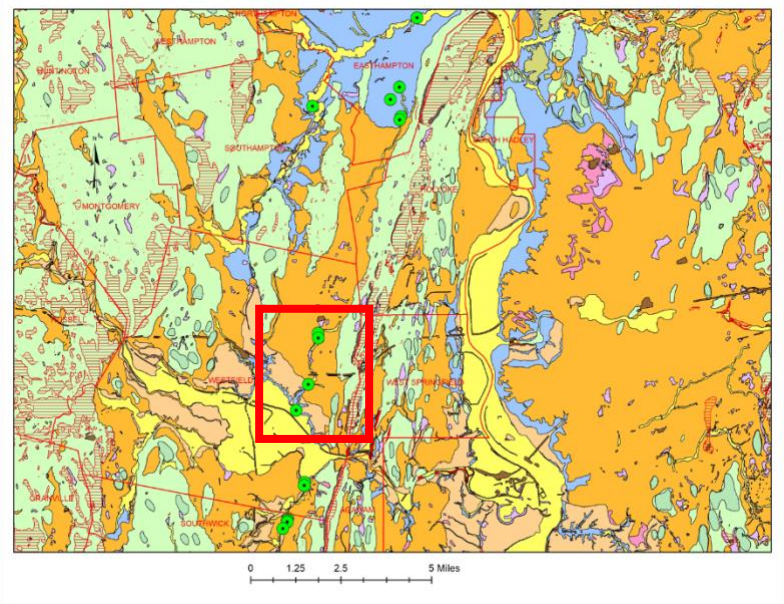

Figure 3 - Map of surficial materials in the Barnes Aquifer region. Municipal well locations shown as green points. (Figure credit to Bob Newton; Emeritus Professor Smith College).

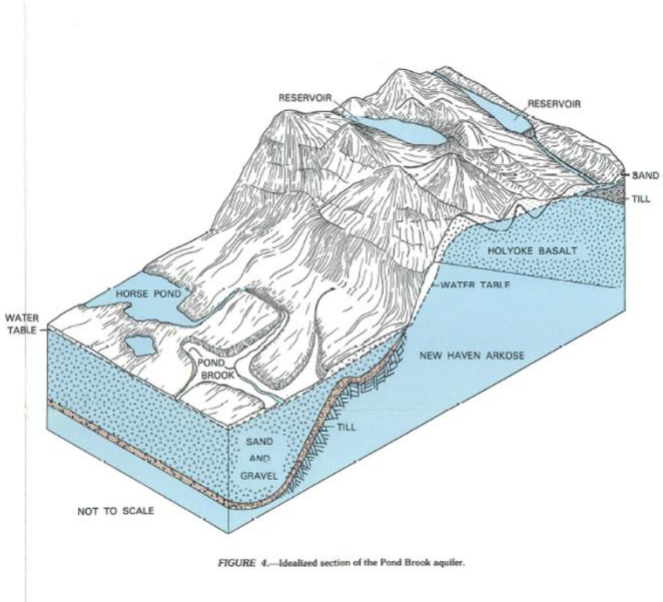

Figure 4 - Idealized geologic cross section of the Pond Brook Aquifer in Westfield, Massachusetts. The cross section depicts the surficial materials, bedrock, and water features of the region. From "Water Resources of the Westfield and Farmington River Basins, Massachusetts", by A. Maevsky and D.G. Johnson, 1990, USGS Hydrologic Atlas (HA) 716.

The prolific water transporting properties of the aquifer have led to significant groundwater well installation in the region (see red points on Figure 5). These wells provide water to the communities of Easthampton, Southampton, and Westfield. Groundwater flows south towards the Westfield River in the southern portion of the aquifer where the Barnes ANG Base is. Municipal wells 1, 2, 7,

and 8 for the town of Westfield are located in this area. The wells receive water from the areas where the Westfield-Barnes Regional Airport is located. Numerous private wells are also located in the sand and gravel deposits and the permeable sedimentary bedrock (Figure 4).

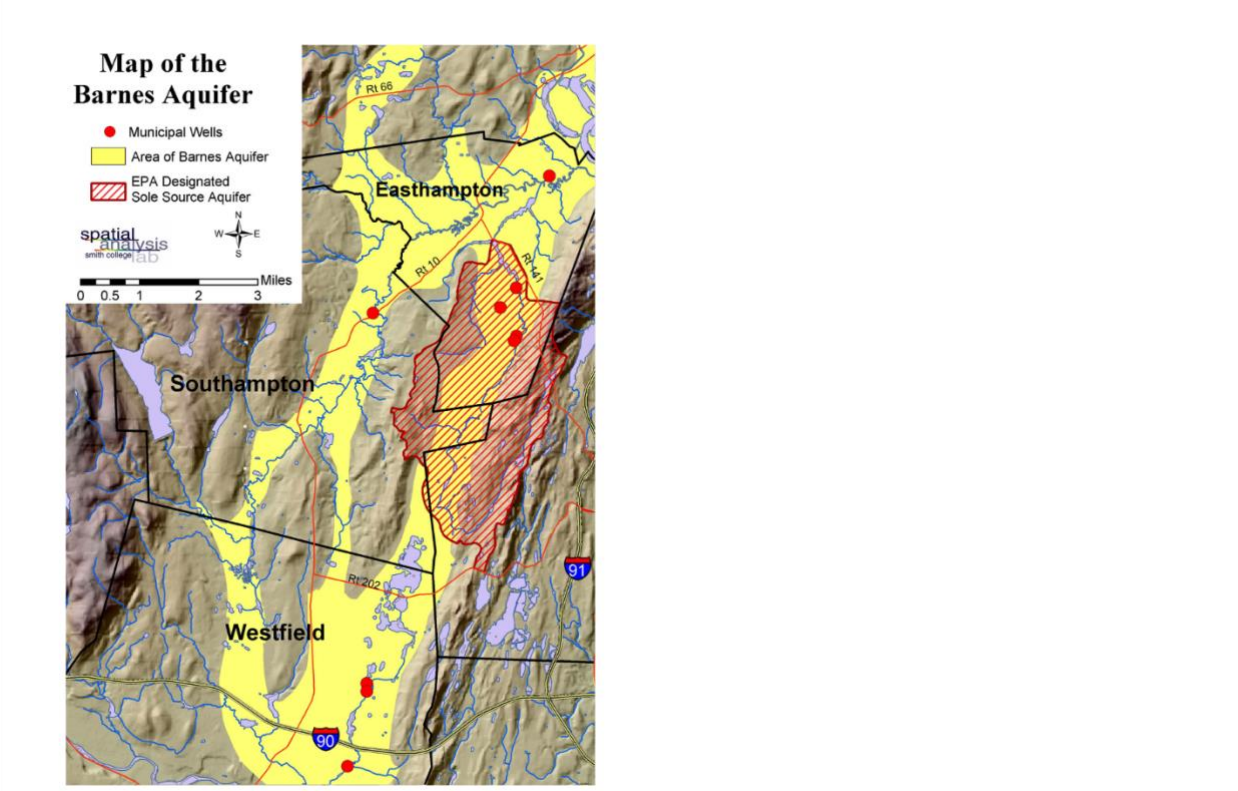

Figure 5 - Map of the Barnes Aquifer and the EPA Designated Sole Source Aquifer within it. Municipal wells are shown as red dots. (Figure credit to Bob Newton; Emeritus Professor Smith College).

5. Overview of Reports and Data

Below key findings and aspects of the reviewed reports are identified:

a. Final Perfluorinated Compounds Preliminary Assessment Site Visit Report (BB&E. 2016):

- 7 potential Areas of Concern identified:
  - Former Fire Training Area (FTA-01)
    - AFFF likely used during training exercises between 1950-1987
  - Stormwater Drainage Basin
  - Hangars 27A and 27B
  - Former Fire Station (Building 004)
  - Current Fire Station (Building 040)
  - Hush House
  - Fire Department Equipment Test Area
- 3 offsite Areas of Concern identified:

    - 2013 civilian aircraft fire
        - Near the intersection of Runways 02 and 15, approximately 1500ft southeast of current Base fire station
        - 5 gallons of AFFF used, infiltrated through cracks in runway
    - 2001 civilian aircraft crash into HFP Sprinkler Corporation
        - 0.5 miles northeast of the northeast corner of the base
        - 50-60 gallons of 3% AFFF solution used, released into nearby parking lot, storm drains, and the ground surface
    - Late 1990s northern soccer fields
        - North of base, 0.5 miles north of Falcon Drive
        - Accidental release of 5 gallons of 3% AFFF into soccer fields, soaked into ground
- Impacted wells
    - 2015 Westfield Well 7 first exhibited trace amounts of PFCs
    - Westfield Wells 7 and 8 are less than 5000ft from the southeast corner of the Base
    - Five additional wells are within a 1-mile radius of the Base

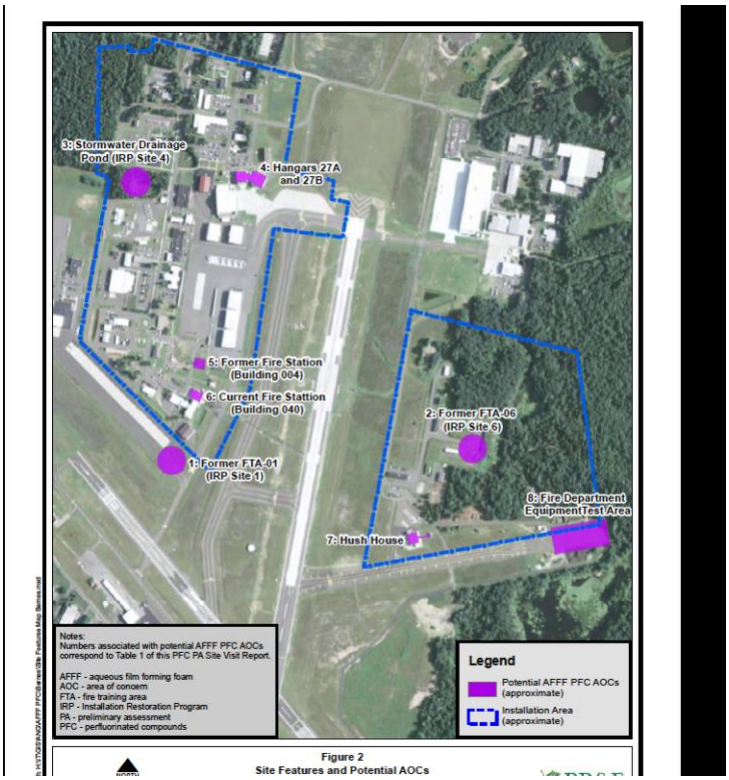

Figure 6 - Map depicting eight potential areas of AFFF/PFC release (Areas of Concern) within the Barnes Air National Guard Base. From "Final Perfluorinated Compounds Preliminary Assessment Site Visit Report, Barnes Air National Guard Base, Westfield, Massachusetts", BB&E, 2016.

Table 1: Preliminary Assessment Report Summary and Recommendations

No.	Potential AFFF PFC AOC	GPS Coordinates		Rationale	Recommendation
		Latitude	Longitude		
1	Former FTA-01 (ERP Site 1)	42.163943°	-72.718612°	AFFF likely utilized at this FTA located on or just south of ANG boundary, exact footprint unclear. FTA activities appear to have extended onto current ANG installation.	Proceed to SI, focus on soil and groundwater.
2	Former FTA-06 (ERP Site 6)	42.164233°	-72.709567°	AFFF likely not utilized due to age of FTAs.	NFA
3	Stormwater Drainage Basin (ERP Site 4)	42.170343°	-72.719542°	Received AFFF discharges from the flight line area and from former floor and trench drains located in the hangars and buildings on the flight line.	Proceed to SI, focus on sediments and groundwater.
4	Hangars 27A and 27B	42.170529°	-72.716208°	No documented AFFF releases.	Proceed to SI, focus on soil and groundwater.
5	Former Fire Station – Building 004	42.166498°	-72.718292°	Floor drains in former station likely went to drywell associated the former facility. Facility used from the 1940s to approximately 1990.	Proceed to SI, focus on soil and groundwater.
6	Current Fire Station – Building 040	42.165504°	-72.717890	No documented AFFF releases. No floor drains.	Proceed to SI, focus on soil and groundwater.
7	Hush House	42.162205°	-72.711083°	One potential documented release likely from original fire suppression test. Any releases would have gone to the sanitary sewer.	Proceed to SI, focus on soil and groundwater.
8	Fire Department Equipment Test Area	42.162271°	-72.705777°	At least three AFFF foam tests conducted; possible earlier use as fire equipment test area in early 1990s.	Proceed to SI, focus on soil and groundwater.

Figure 7 - Table of assessments and recommendations for each Area of Concern from the preliminary site assessment of the Barnes Air National Guard Base in 2016. From "Final Perfluorinated Compounds Preliminary Assessment Site Visit Report, Barnes Air National Guard Base, Westfield, Massachusetts", BB&E, 2016.

b. MA DEP NOES & Private Well Sampling Results (2017- Present):

- Between April-August 2017, 75 private wells in Westfield sampled for PFAS
  - 4 wells exceeded MassDEP ORS guidelines (70ppt) on initial sampling – carbon filtration systems installed
  - 4 wells exceeded guidelines on Lower Sandy Hill Road (3) and Buck Pond Road (1)
- 19 wells resampled September-October 2018
  - PFAS concentration in all wells declined - PFAS remained below MassDEP ORS guidelines and EPA health advisory at the time

c. Final Phase 1 Regional Site Inspection Report for Perfluorinated Compounds (AMEC. 2018):

Results included and are summarized in Figure 9

- In the SI (AMEC. 2018) 7 Areas of Concern were investigated (Figure 8 - Table of site inspection field activities conducted at seven Areas of Concern on the Barnes Air National Guard Base during the Phase I Regional Site Inspection in 2018. From "Final Report, FY16 Phase I Regional Site Inspections for Perfluorinated Compounds Massachusetts Air National Guard – 104th Fighter Wing, Barnes Air National Guard Base, Westfield, Massachusetts", Amec Foster Wheeler, 2018.

- FTA-01
    - Soil samples: 2 samples both 0-2ft below ground; some PFCs detected but none exceeding screening criteria
    - GW samples: only PFOS exceeded screening criteria
- Stormwater Drainage Basin
    - Soil samples: 2 samples both 0-2ft below ground; some PFCs detected but none exceeding screening criteria
    - GW samples: no PFCs above screening criteria
- Hangars 27A and 27B
    - Soil samples: 6 samples, 0-2ft below ground and 13-15ft below ground; PFOS detected
    - GW samples: only PFOS exceeded screening criteria
- Former Fire Station (Building 004)
    - Soil samples: 4 samples, 0-2ft below ground and 13-15ft below ground; some PFCs detected but none exceeding screening criteria
- Current Fire Station (Building 040)
    - Soil samples: 6 samples, 0-2ft below ground and 13-15ft below ground; some PFCs detected but none exceeding screening criteria
    - GW samples: PFOS and PFAS above screening criteria
- Hush House
    - Soil samples: 4 samples, 0-2ft below ground and 13-15ft below ground; only PFOS above screening criteria
    - GW samples: only PFOS exceeding screening criteria
- Fire Department Equipment Test Area
    - Soil samples: 2 samples both 0-2ft below ground; some PFCs detected but none above screening criteria
    - GW samples: no PFCs above screening criteria

The following SI field activities were completed:

PRL Name	Analyzed Parameters	Soil Borings	Soil Samples	Groundwater Samples Existing Wells	Groundwater Samples Temporary Wells	Surface Water Samples	Sediment Samples
1. Former FTA-01 (IRP Site 1)	PFCs	2	2	0	1	0	0
3. SW Drainage Basin (IRP Site 4)	PFCs	0	0	1	0	0	2
4. Hangars 27A and 27 B	PFCs	3	6	0	1	0	0
5. Former Fire Station (bldg. 004)	PFCs	2	4	0	0	0	0
6. Current Fire Station (Bldg. 040 S)	PFCs	3	6	0	1	0	0
7. Hush House	PFCs	2	4	0	1	0	0
8. Fire Department Equipment Test Area	PFCs	2	2	0	1	0	0

Figure 8 - Table of site inspection field activities conducted at seven Areas of Concern on the Barnes Air National Guard Base during the Phase I Regional Site Inspection in 2018. From "Final Report, FY16 Phase I Regional Site Inspections for Perfluorinated Compounds Massachusetts Air National Guard – 104th Fighter Wing, Barnes Air National Guard Base, Westfield, Massachusetts", Amec Foster Wheeler, 2018.

PRL	Screening Criteria Exceedance		Recommendation
	Soil	GW	
PRL 1: Former FTA (IRP Site 1);	Inc.	X	Soil investigation to determine if PFCs exceed screening criteria off-Base. Groundwater (GW) investigation to determine the nature and extent of the confirmed release.
PRL 3: Stormwater Drainage Basin;			NFA
PRL 4: Hangars 27A & 27B;		X	GW investigation to determine the nature and extent of the confirmed PFC release.
PRL 5: Former Fire Station, Bldg. 004;		X	GW investigation to determine the nature and extent of the confirmed PFC release.
PRL 6: Current Fire Station, Bldg. 040;		X	GW investigation to determine the nature and extent of the confirmed PFC release.
PRL 7: Hush House		X	GW investigation to determine the nature and extent of the confirmed PFC release.
PRL 8: Fire Department Equipment Test Area.	Inc.	Inc.	Soil and GW investigation to determine if PFCs exceed screening criteria off-Base.

Figure 9 - Table of screening criteria exceedances of PFCs in soil and groundwater at the Barnes Air National Guard Base and recommendations for further investigations. From "Final Report, FY16 Phase I Regional Site Inspections for Perfluorinated Compounds Massachusetts Air National Guard – 104th Fighter Wing, Barnes Air National Guard Base, Westfield, Massachusetts", Amec Foster Wheeler, 2018.

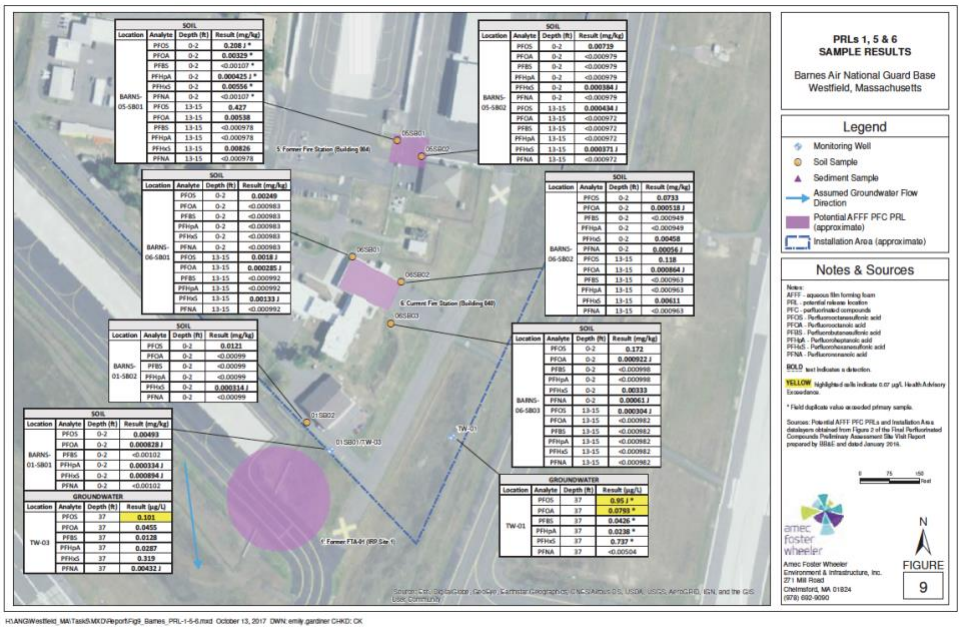

Figure 10 - Map depicting the PFC concentrations at soil and groundwater sampling locations within the Barnes Air National Guard Base. Results highlighted in yellow represent Health Advisory Exceedances of PFC concentrations. Sampling locations are centered around AOCs 1 (Former Fire Training Area), 5 (Former Fire Station), and 6 (Current Fire Station). From "Final Report, FY16 Phase I Regional Site Inspections for Perfluorinated Compounds Massachusetts Air National Guard – 104th Fighter Wing, Barnes Air National Guard Base, Westfield, Massachusetts", Amec Foster Wheeler, 2018.

d. Final Expanded Site Inspection Report for PFAS. (Parsons. 2020)

In 2020 the final expanded site inspection was completed. Parsons (2020) summarized the process as follows:

"The NGB/A4VR performed a Preliminary Assessment (PA) (BB&E, 2016) and Site Inspection (SI) (Amec Foster Wheeler, 2018) at the Barnes ANGB in accordance with the CERCLA process for PFAS in soil, surface water, sediment, and groundwater. The USEPA identifies the SI as the on-site investigation to determine what hazardous substances are present and if they are being released to the environment. The previous SI activities were confined to seven on-Base previously identified areas, now called Areas of Concern (AOCs), on or near Base. The SI recommended additional investigation at the seven AOCs (Amec Foster Wheeler, 2018). Therefore, the ESI was conducted to augment the data collected in the SI and determine if there are off-Base upgradient sources and/or downgradient impacts to off-Base receptors. Two AOCs (AOCs 1 and 8) were identified as requiring further investigation during this ESI because they are located off-Base and were not fully investigated during the SI."

Figure 11 briefly summarizes what was done, and summary findings are presented below and in Figure 12.

- **Soil**

    - FTA-01
        - Highest PFAS/PFOS on Base found 13-15ft below ground
    - Fire Department Equipment Test Area
        - PFOS, PFHxS, PFHpA, PFAS detected at 13-15ft below ground
    - Stormwater Drainage Basin
        - No PFAS detected
- **Groundwater**
    - FTA-01 – PAL exceeded in shallow, intermediate, and deep GW zones
    - Fire Department Equipment Test Area – PAL exceeded in shallow, intermediate GW zones – detected upgradient as well, indicating contamination north of base
    - Stormwater Drainage Basin – detected
    - Hangars 27A and 27B – PAL exceeded in shallow, intermediate GW zones
    - Former Fire Station (Building 004) – PAL exceeded in shallow, intermediate GW zones
    - Current Fire Station (Building 040) – PAL exceeded in shallow, intermediate GW zones
    - Hush House – PAL exceeded in shallow, intermediate GW zones
    - Near base, highest PFC concentrations in shallow wells; further downgradient highest concentrations in intermediate wells
- **Surface water**
    - Arm Brook – PAL exceeded downgradient FTA-01
    - Pond Brook – PAL exceeded downgradient FTA-01, Hush House, FDETA
    - Powdermill Brook – PAL exceeded 11800ft downgradient of BANGB; potential additional PFAS source
    - Westfield River – detected at Northern bank
- **Sediment**
    - Only PFOS detected in Pond Brook, exceeding PAL

i. Source areas

FTA-01 and the Current Fire Station (Building 040) were identified as the primary source areas. Hangars 27A and 27B, Former Fire Station (Building 004), and the Hush house were identified as secondary source areas.

ii. Drinking water impacts:

PFCS were detected in four Westfield municipal wells downgradient of the Barnes ANG Base. Over 40 private wells in Westfield detected PFCS. Lower Sandy Hill Road had the highest PFOA and PFOS concentrations, including contamination found in bedrock. A continuous PFAS plume extended from the Barnes ANG Base to the end of Runway 2-20 at the Westfield-Barnes Regional Airport beyond the turnpike to the south.

Table 1
Expanded Site Inspection Sampling Summary
Expanded Site Inspection Report for PFAS
Barnes ANGB, Westfield, Massachusetts

AOC	AOC Name	Media Impacted above PALs per SI	Number of SBs	Number of Monitoring Wells		Number of Samples				
				Existing	New	SO	GW	SW	SD	ST
1	Former FTA-01 (IRP Site 1)	GW and SO	5	3	5	11	18	0	0	1
3	Stormwater Drainage Basin (IRP Site 4)	None	2	0	1	4	2	0	0	0
4	Hangars 27A and 27B	GW and ST	0	0	2	0	4	0	0	1
5	Former Fire Station (Building 004)	GW and ST	0	0	2	0	4	0	0	1
6	Current Fire Station (Building 040)	GW and ST	0	0	2	0	4	0	0	3
7	Hush House	GW and ST	0	0	2	0	4	0	0	1
8	Fire Department Equipment Test Area	GW, SO, and ST	6	0	2	13	4	0	0	1
Upgradient	Not applicable	GW	0	0	4	0	10	0	0	2
Downgradient	Not applicable	GW, SW, and SD	0	0	35	0	74	13	13	0

Notes:
GW - groundwater
SW - surface water
SB - soil boring
SO - soil
SD - sediment
ST - storm water

Figure 11 - Table of sampling activities at the Areas of Concern within the Barnes Air National Guard Base and off-base upgradient and downgradient locations completed during the Final Site Inspection in 2020. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

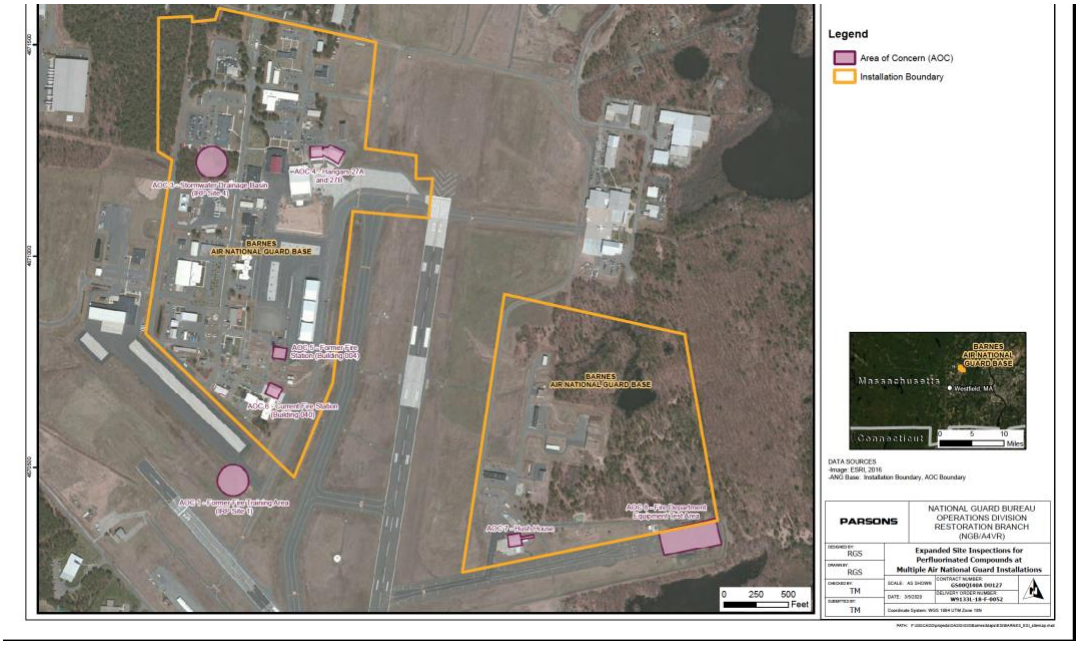

Figure 12 - Map depicting the Areas of Concern, areas with potential AFFF/PFC contamination, within the Barnes Air National Guard Base. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

6. PFAS Plume and Source Areas

a. Soil Contamination

Three areas were investigated in the ESI for soil contamination. The three AOCs (1, 3, and 8) all had PFAS values above the PALs (Figure 13). These areas are likely source areas of PFAS into the groundwater system.

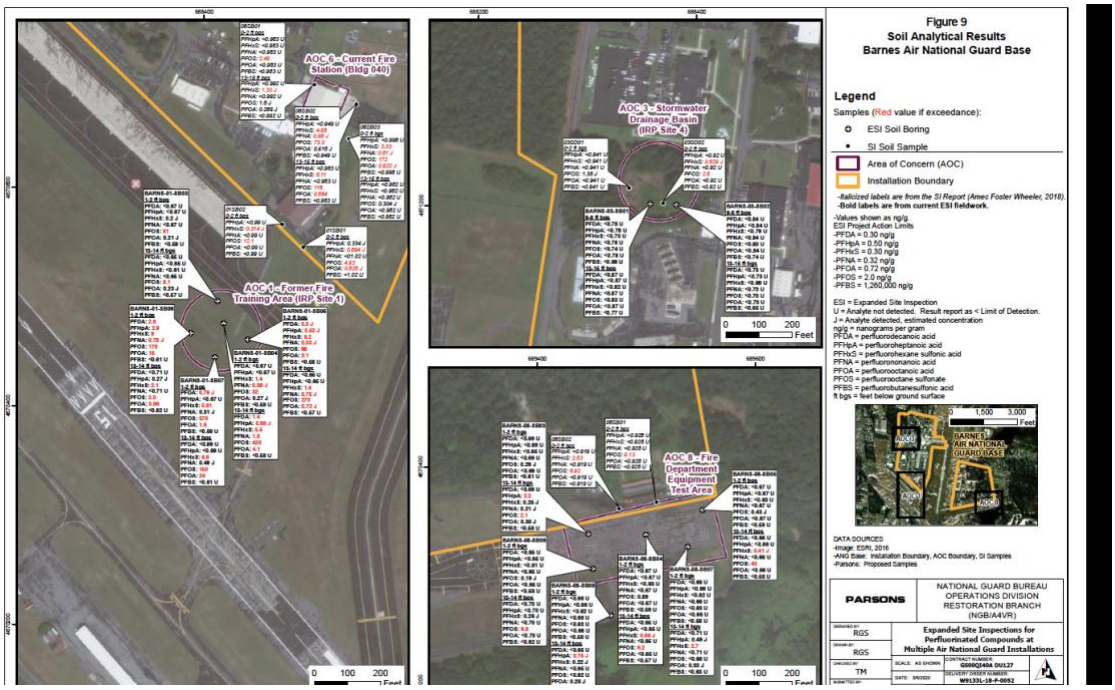

Figure 13 - Map showing the soil analytical results at the sampling locations within the Areas of Concern on the Barnes Air National Guard Base. Exceedances of the Project Action Limits of PFC concentrations are highlighted in red. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

b. Groundwater contamination

Figure 14 depicts the findings from the groundwater sampling in and around the AOC areas. Significant levels of PFCs were found at all sites and depths within the aquifer system.

Figure 14 - Map showing the groundwater analytical results of PFC concentrations at the groundwater sampling locations within the AOCs on-base and downgradient wells off-base. Exceedances of the Project Action Limit of PFC concentrations are highlighted in red. Groundwater flow direction is depicted by blue arrows. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

c. Plume Size

Figure 15 depicts a representation of the size and extent of the sum of the 6 most common PFCS compounds detected across the site. This interpretation is a projection of the size of the plume to the surface based on a 3-dimensional interpolation of the data collected in the ESI. As depicted, contamination was found everywhere that was sampled across the site. Additionally, Figure 15 shows the locations of off-site private wells where contamination was found. As is apparent in the contours of the PFCS values, contamination has migrated extensively across the site and into other surface waters and groundwaters. As discussed below, the representation of the plume on this map is smaller than the actual plume.

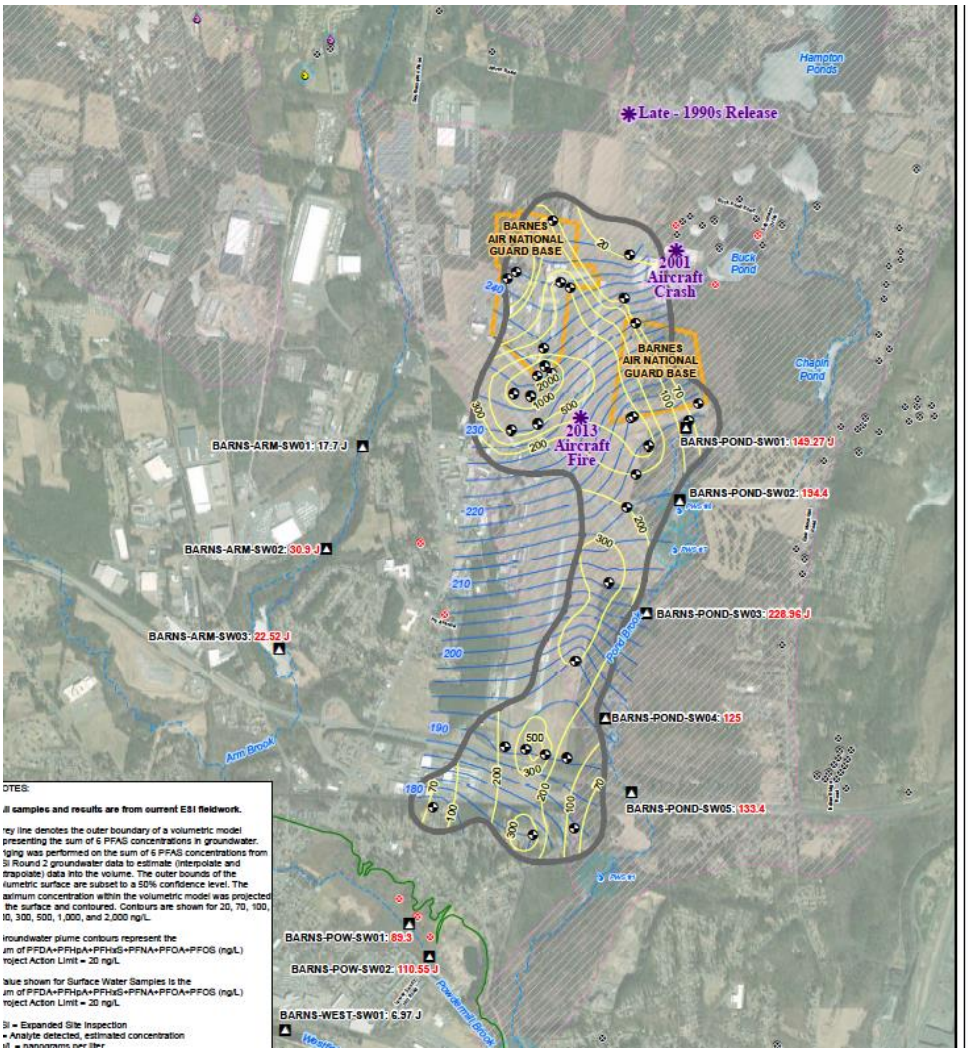

Figure 15 - Map depicting the size of the PFC contaminant groundwater plume as determined from the Final Site Inspection in 2020. The locations of groundwater monitoring wells, private drinking water wells, and public water supply wells are shown. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

d. Plume Migration and Characteristics

The radar plots of groundwater and surface water PFCS detections show similar patterns (Figure 16 and Figure 17). These plots demonstrate the dominant PFCS constituent in the sample. Most PFCS compounds in industrial chemicals are mixtures of different compounds of varying composition and concentrations. Thus, by looking at the relative proportion of these you can identify possible source composition. As summarized in the ESI:

"Primary source AOCs with history of routine AFFF storage, handling, or use exhibit a characteristic PFAS signature dominated by PFOS and PFHxS at relatively elevated concentrations."

This suggest that the groundwater and surface water contamination and plumes are related to AFFF chemicals.

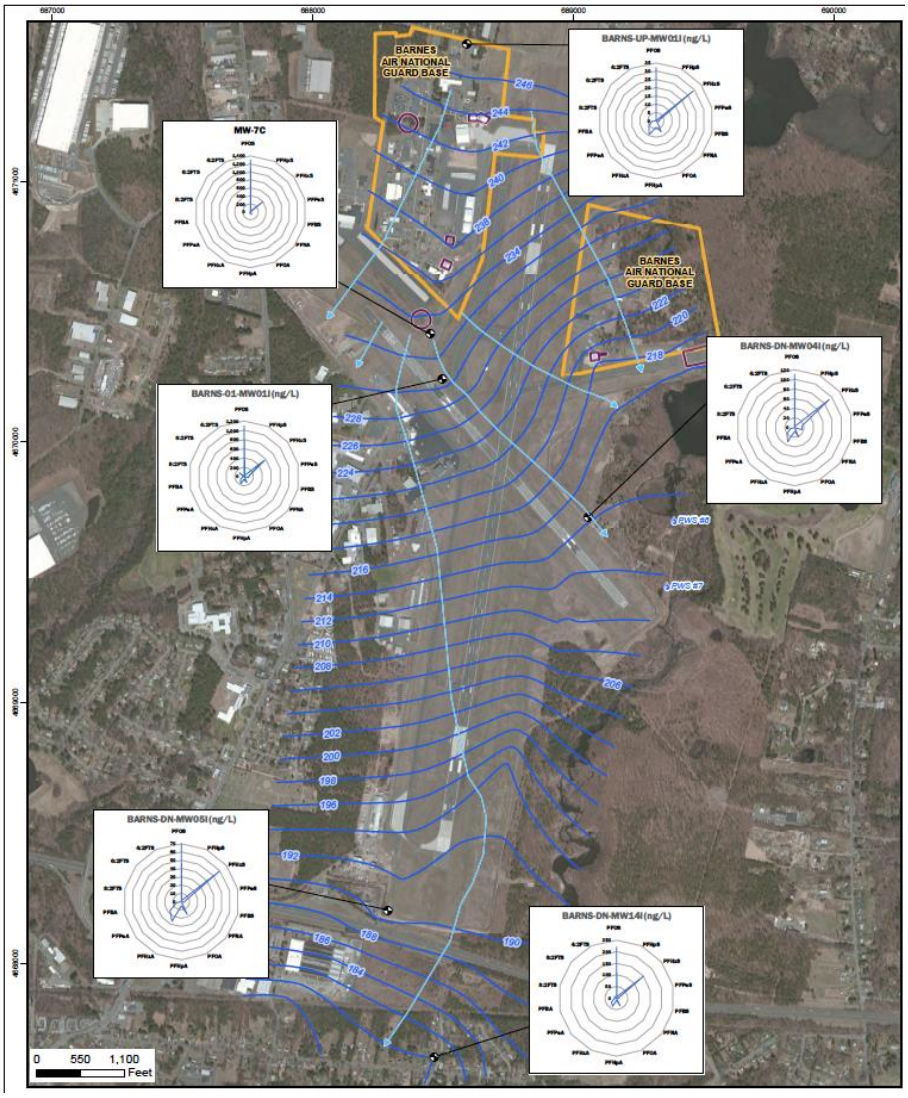

Figure 16 - Map depicting the locations where PFCS proportional analyses for groundwater were conducted during the Final Site Inspection of the Barnes Air National Guard Base in 2020. Radar charts show the relative concentrations of PFCS compounds at each site. Blue arrows depict groundwater flow direction. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

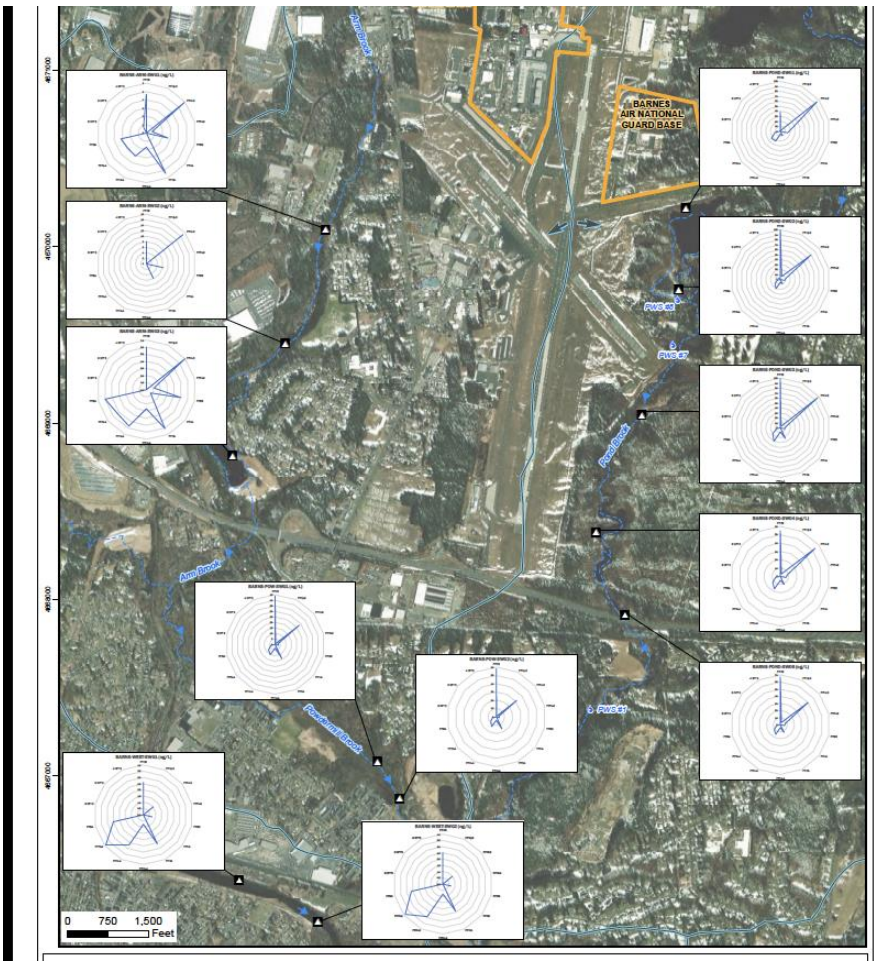

Figure 17 - Map depicting the locations where PFCS proportional analyses for surface water were conducted during the Final Site Inspection of the Barnes Air National Guard Base in 2020. Radar charts show the relative concentrations of PFCS compounds at each site. Blue arrows depict surface water flow direction. Gray arrows depict local surface water flow direction. From "Final Expanded Site Inspection Report for Per- and Poly-Fluoroalkyl Substances (PFAS) at the Barnes Air National Guard Base Westfield, Massachusetts", Parsons, 2020.

7. Critical Findings and Concerns

a. Key Findings

The 2020 ESI report is the most comprehensive analysis of the PFCS contamination at the Barnes ANG Base. The investigation collected important information regarding the hydrology and the extent of PFCS contamination across the site and the surrounding environment. Below I briefly summarize what I find as key elements resulting from the new data. Horizontal hydraulic gradients (the main driver of groundwater flow) across the site are incredibly steep with values approaching 8ft/1000ft. These gradients drive significant groundwater flow under the area and are the main flux of water through the site. This flow has quickly moved PFCS across the site, up to perhaps 200 feet per year. Groundwater flow has a strong downward component across most of the site, with downward gradients of more than 8ft/100ft. The magnitude of these downward directed gradients far exceed the horizontal flows.

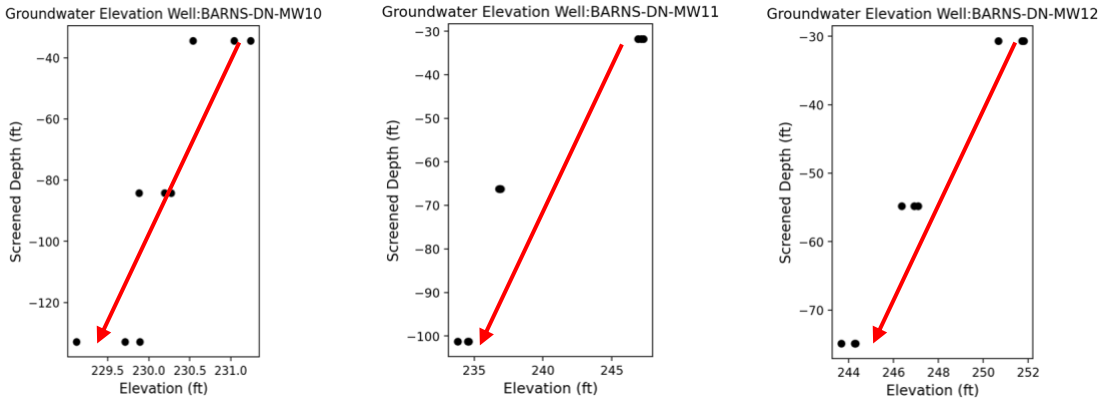

Figure 18 - Vertical hydraulic heads within the aquifer from select monitoring wells at the site. Steep downward focused hydraulic head gradients are observed. Data from Parsons (2020)

Sampling of groundwater wells for the sum of the 6 major PFCS compounds found that a large plume of contamination was present across the entirety of the aquifer studied. The plume is (Figure 15) found at all depths within the aquifer. It is laterally extensive with some areas around potential release sites having significantly higher concentrations than other locations in the subsurface. The high hydraulic gradients in the horizontal and vertical dimensions have led to the widespread transport of PFCS across the site and into downgradient surface and groundwater. Characteristics of the PFCS compounds detected in the downgradient surface and groundwaters are similar in composition to PFCS compounds in soil and groundwater across the site (Figure 16 and Figure 17).

The extent of the groundwater contamination is contrasted by the punctuated and localized soil contamination. The examination of the 8 AOCs revealed significant soil contamination in the AOC1 and AOC8 areas (Figure 13). The reason for the differences in the soil and groundwater samples is the flow and transport of the PFCS through the vadose zone and into the groundwater.

The ESI (Parsons, 2020) revealed the potential for multiple sources and pathways of PFCS into the aquifer system (Figure 15). These are both on-base and off-base sources, including releases with known dates and locations.

b. PFCS in Soil Compared to Groundwater

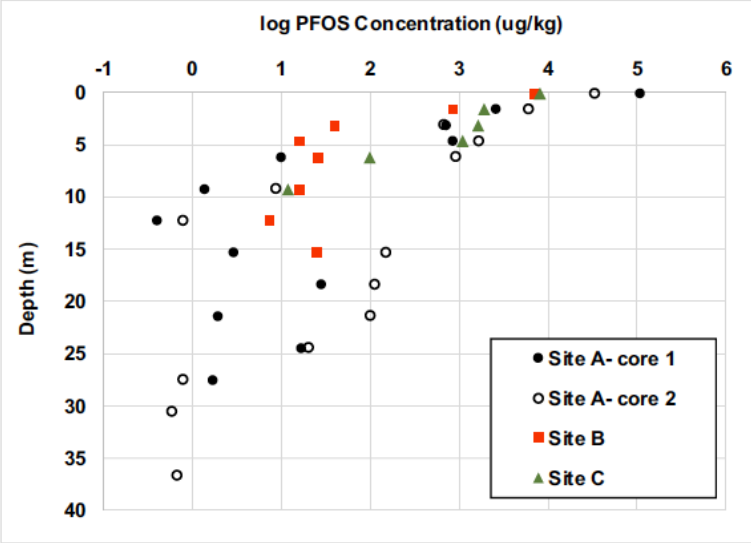

Fig. 2. Example depth profiles of PFOS soil concentrations developed using data from the U.S. Air Force AFFF Impacted-Site database.

Figure 19 - Example depth profiles of PFOS soil concentrations developed using data from the US Air Force AFFF Impacted-Site database. From Anderson et al. (2019)

"It is noteworthy that soil concentrations reported for PFCS at contaminated sites are often orders-of-magnitude higher than typical groundwater concentrations, ranging up to parts-per-million levels. Thus, research studies, site investigations, and modeling efforts characterizing PFCS transport in soil and the vadose zone need to be implemented with this in mind. The concentrations encountered at any given site will of course depend upon the nature of the PFCS source, the timeframe of contamination, site conditions, and many other specific factors."

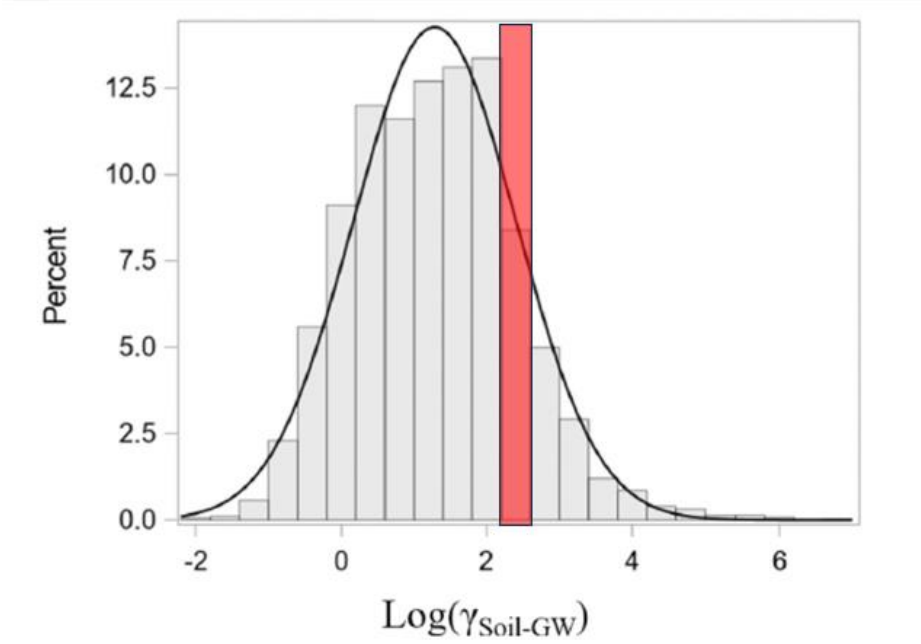

Figure 20 - Ratio of soil PFCS concentrations to groundwater concentrations for airport sites across the United States. The red bar represents where the Barnes Air National Guard Base falls within this distribution (Anderson et al., 2019).

The plot in Figure 20 shows the ratio of soil PFCS concentration to groundwater concentrations for airport sites across the US. Barnes ANG Base on this scale falls around a value of 2-3 (a sitewide ratio of ~200). This suggests that the soils on site are consistent with the magnitude of groundwater contamination in most of the plume based on comparisons to other sites.

c. Groundwater Concentrations

"Vertically, the PFAS concentrations were found throughout the aquifer (shallow, intermediate, and deep zones). Generally, near AOC sources the highest PFAS concentrations were found in the shallow wells screened at the water table, whereas farther downgradient of the AOCs, the highest PFAS concentrations were predominantly found in the intermediate groundwater zone."

It's not clear that the magnitude of soil contamination across the aquifer system is consistent with the concentrations and extent of the groundwater plume.

8. Concerns and Observations

The geology of the aquifer is poorly characterized nor conceptualized - disappointing that not a single cross-section or 3-dimensional map of the contaminant distribution was presented.

A major shortcoming of the analyses to date is an understanding the of subsurface conditions beneath the site. It clearly has an important impact on the nature and extent of the PFCS contamination across the site.

The widespread distribution of PFCS through the aquifer is a major finding in the ESI report and contrasts strongly with this statement from the 2016 report:

> "In general, groundwater contamination associated with historic contaminated sites at the Base does not migrate significantly either vertically or horizontally. Based on this, potential releases of AFFF to groundwater also may not migrate significantly."

I am concerned that the consultants who have worked on this site have over-simplified the hydrology, geology, and hydrogeology. This suggests to me that in past the ANG and/or the consultants don't truly understand the aquifer and its complexities.

The migration rates through vadose zone are high.

The data presented in the study suggest that migration rates through the vadose zone (the area from the ground surface to water table) is extremely high. This is the reason why the extent of the groundwater contamination is so large. This has implications for the mass transfer of PFCS compounds to wells and surface water.

The lack of focus on bedrock flow and transport is a major issue and an indication of the bias in the conceptual understanding of these systems.

PFCS contamination was found in bedrock wells downgradient of the site. The bedrock was not investigated in the ESI. Given the presence of bedrock wells, site geology, and site hydrogeology, it is expected that the PFCS have migrated significantly into the bedrock.

The analysis of the hydraulic data needs to be expanded beyond what is presented in the reports.

Additional focus should be on determining the hydraulic connection between the shallow and deep parts of the aquifer. The downward hydraulic head gradients are very large and could be explained perhaps by a lack of hydraulic connection.

The plume contour maps should have been extended to samples from private and public wells outside of the existing area.

The map of plume geometry and distribution from the ESI (Parsons, 2020) in Figure 15 is not adequate. It should include the off-site surface waters since they are directly connected to the aquifer and the overburden private wells. For example, in Figure 15 you can see the plume extent does not reach out to town wells 7 and 8 while it clearly should. Additionally, contours should extend to the groundwater dominated surface water to the east and west of the site.

The description of the contouring and presentation of the 3D volume is not adequate.

The full 3D volume needs to publicly available. The description presented in the ESI is not sufficient to independently arrive at the exhibited map.

The analysis assumes a certain amount of stationarity in the system.

Correlating sources to current GW observations is not appropriate since clearly migration rates in the aquifer are extremely high. This means that the current distribution of PFCS in the aquifer cannot necessarily be tied directly back to specific sources. As the report discussed, there are likely additional sources of PFCS into the system, perhaps from the early 1990's upgradient release or elsewhere.

9. Recommendations – Site Conceptualization

In reviewing the reports and my prior experience working on the hydrogeology of the area, I am providing the following recommendations:

- There needs to be a full-scale geological investigation, including geophysical surveys (incl. Airborne EM and depth to bedrock mapping) and the development of a 3-dimensional solid model of the aquifer and upper bedrock units.
- An aquifer scale hydrogeological flow and transport model needs to be developed to understand the feasibility of transport scenarios and source pathways.
- Environmental tracers should be collected to test the age distribution of the PFCS (see Bennington study; Kim et al, 2023) and source distribution. This will provide key constraints on the groundwater model and the timing of the releases.
- A systematic soil sampling across site and upgradient locations should be undertaken.
- No remediation strategies should be developed without this information.
- The bedrock aquifer needs to be sampled, characterized, and modeled.
- Monitoring wells should be installed to the west of the runway.

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Appendix I - Additional Reports/Studies Reviewed

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