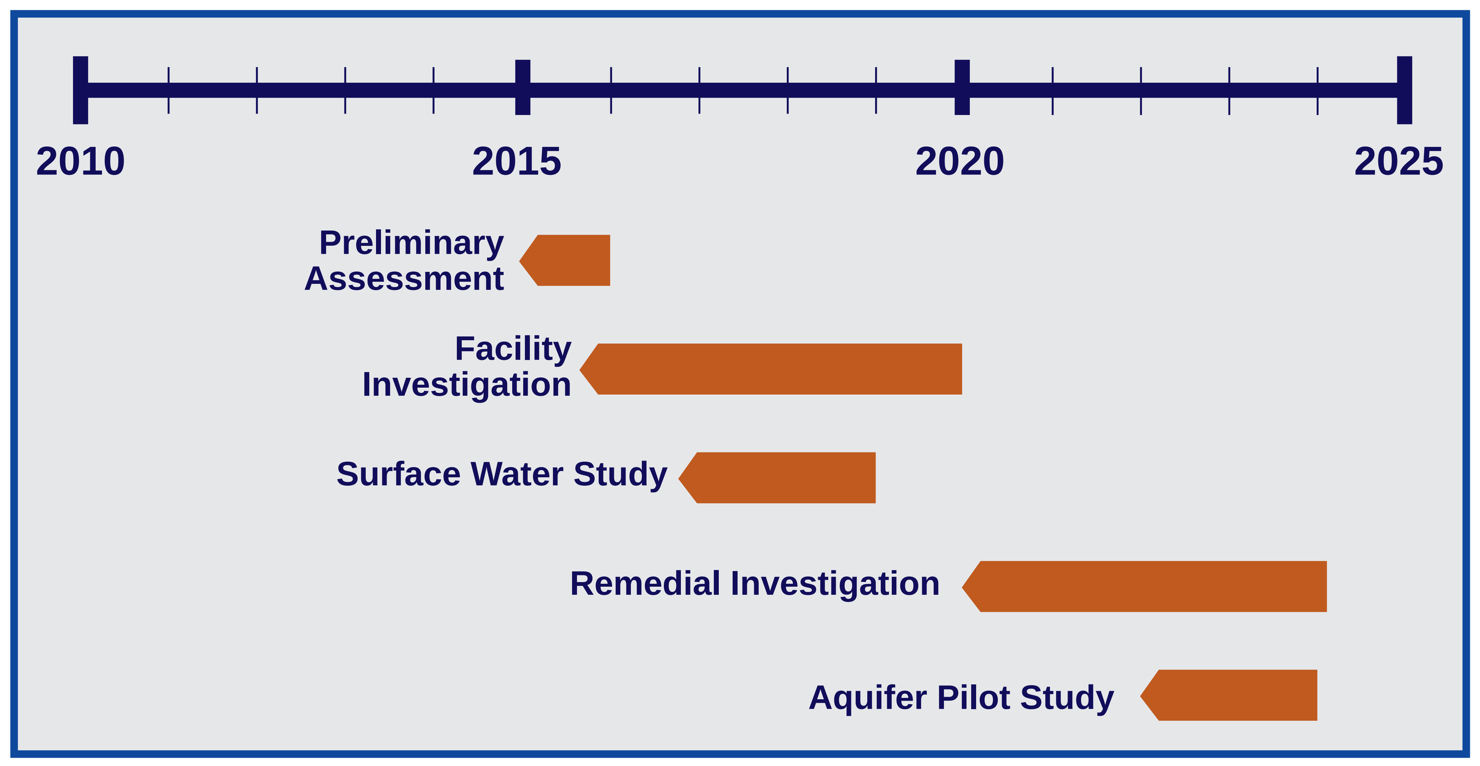
PFAS Remedial Investigation at Biddle Air National Guard Base

THE OBJECTIVE OF THE REMEDIAL INVESTIGATION:

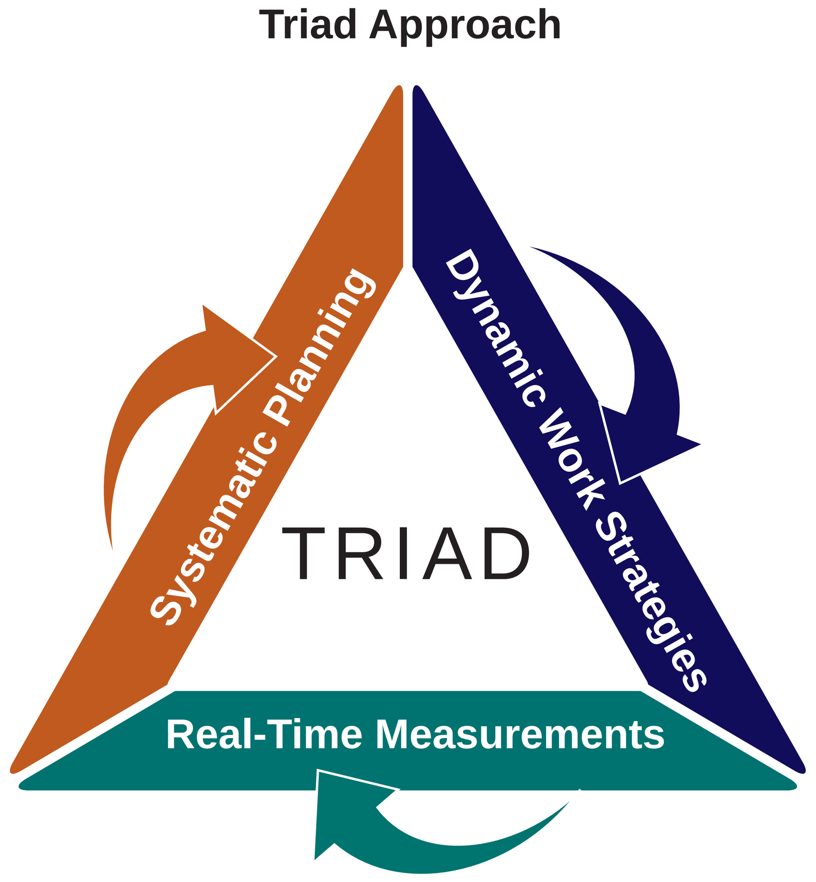
PFAS issues at Biddle Air National Guard Base (ANGB) were first discovered in 2014 triggering ongoing investigations. The current phase of investigation is the Remedial Investigation (RI) initiated in 2019. The RI gathers environmental data needed to delineate the nature and extent of PFAS at Biddle ANGB and to evaluate the potential risk to human health and the environment. The RI data will be used to provide recommendations for further investigation and assist the selection of remedial alternatives where unacceptable risks are present. To date, the majority of RI activities have been completed on-Base or within the unnamed tributary leaving the Biddle ANGB.



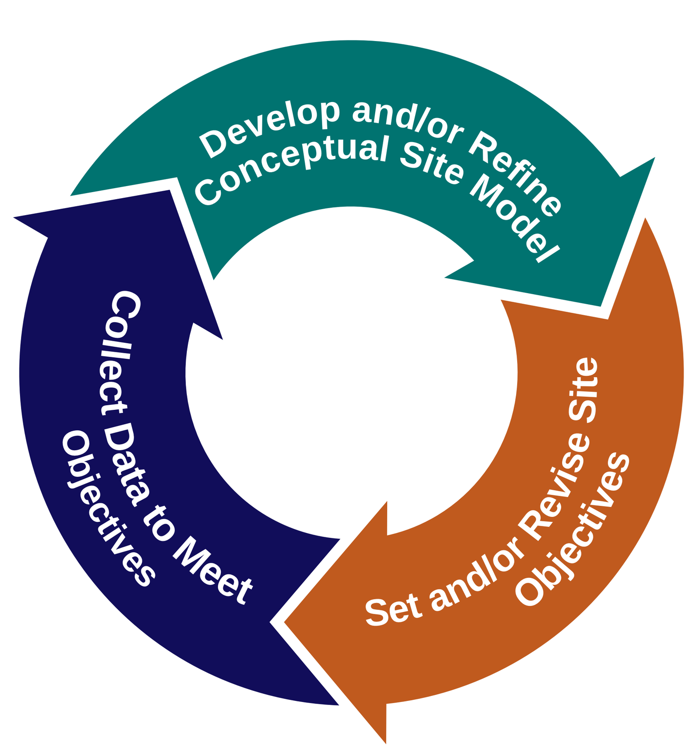
INVESTIGATION APPROACH:

The RI has been conducted using the Triad Approach and elements of Adaptive Management to address the challenges and rapidly evolving regulatory environment of PFAS. This process seeks to engage and collaborate with regulatory stakeholders to facilitate decision-making and to collect data in a phased sequence where each phase is built upon results of the previous phase. Three significant phases of work have been performed during the RI at Biddle ANGB. Between each phase of work, the ANG, Environmental Protection Agency (EPA), and Pennsylvania Department of Environmental Protection (PADEP) engaged in collaborative planning and data evaluation meetings. Investigative activities included collection of several hundred soil, surface water, sediment and groundwater samples, installation of 36 monitoring wells, aquifer testing, geophysical surveying, and straddle packer testing.

Triad Approach

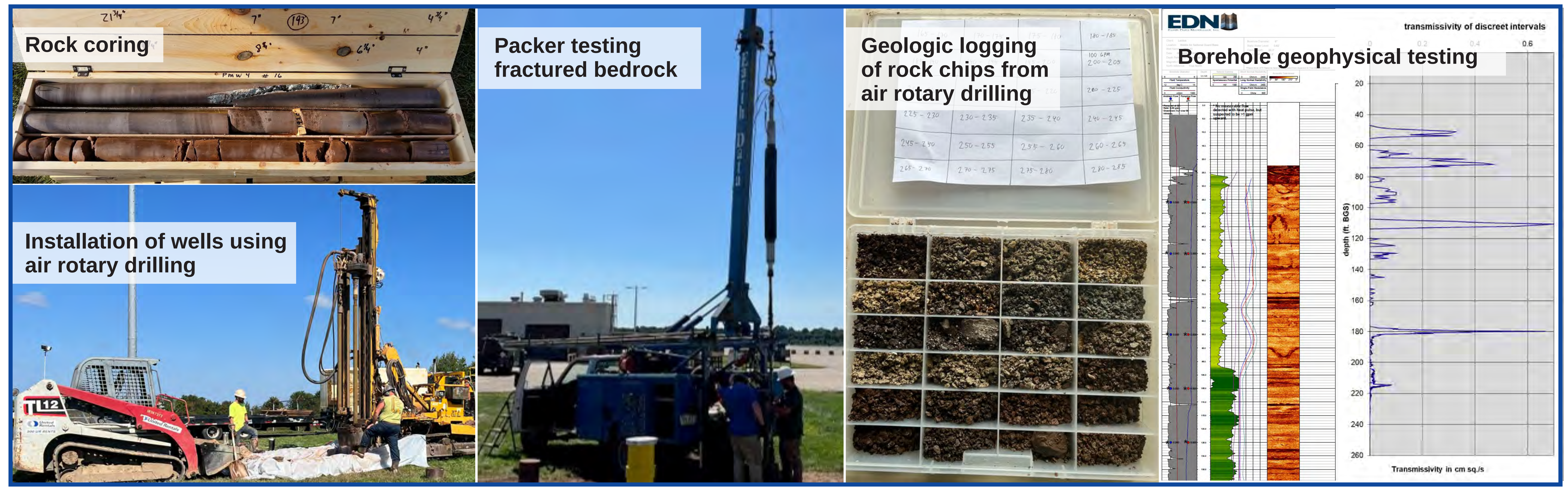


Adaptive Management



INVESTIGATION METHODS:

Characterization of the PFAS at Biddle ANGB requires a variety of methods to understand its interaction with environmental media.



RESULTS:

The RI data were used to develop a conceptual understanding of PFAS at Biddle ANGB, evaluate risks to human health and the environment and to inform future actions.

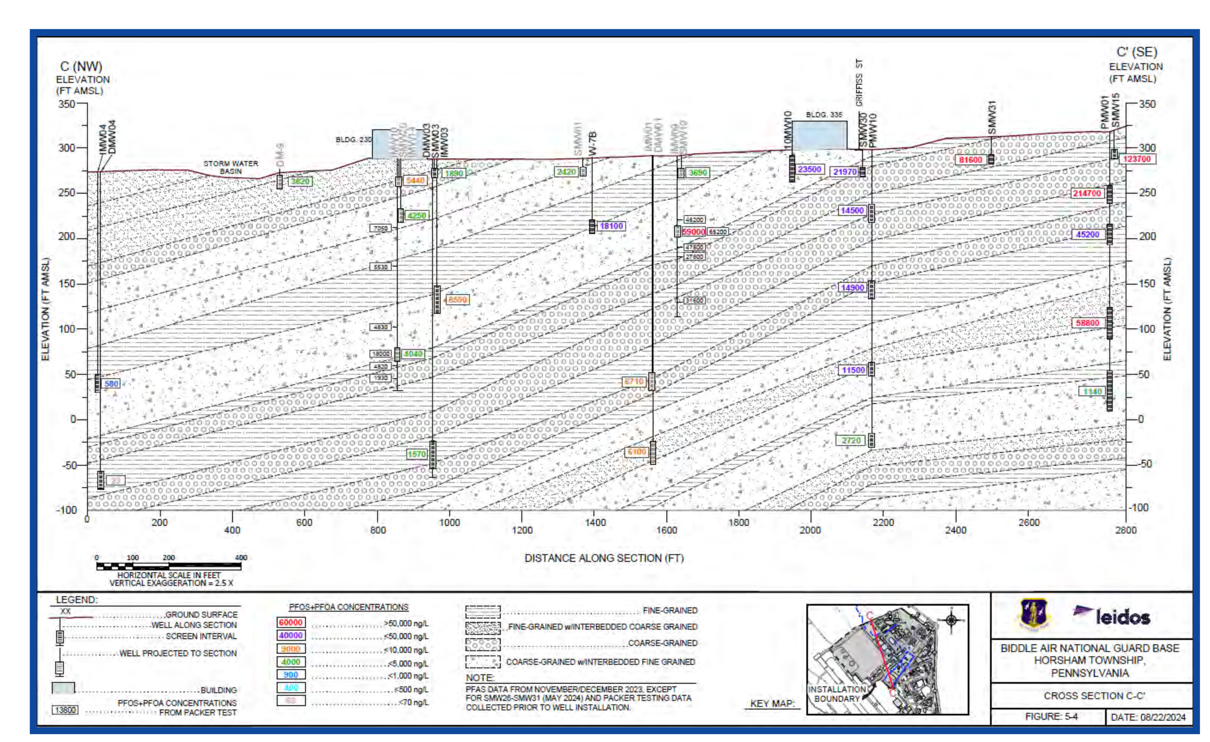
The Conceptual Site Model (CSM) supports multiple PFAS sources and transport mechanisms for the PFAS concentrations found in groundwater at Biddle ANGB.

- Data indicate a substantial source area beyond the southwestern corner of Biddle ANGB. PFAS from this off-Base source reached the shallow groundwater zone and migrated both laterally and downward along preferential pathways.
- Potable water supply wells at Biddle ANGB have influenced migration of groundwater for decades. Once PFAS-impacted groundwater entered the Base water supply it was conveyed across the facility in potable water, sanitary sewer, and steam heat systems. These utilities conveyed PFAS-impacted water around the Base which leaked into the subsurface.
- Smaller PFAS releases within Biddle ANGB contributed PFAS to the environment and became commingled with PFAS from upgradient source(s).
- Local and regional surface water and sediments were impacted via discharge of impacted groundwater, flushing of residual PFAS during precipitation events, and impacted stormwater utilities.

The Risk Assessment examined risks for various exposure scenarios (resident/worker, ingestion/direct contact, etc.).

- Human health risks from exposure to PFOS in soil under a conservative hypothetical residential land use scenario were found to be unacceptable; however, soil risks for workers were acceptable. Human health risks from drinking untreated groundwater were found to be unacceptable due to the presence of PFOS, PFOA, PFHxS, and PFNA.
- Ecological risks were acceptable at most of the Biddle ANGB areas of concern (AOCs). However, ecological risks were unacceptable from exposure to PFOS in soil, sediment, and surface water at the Stormwater Basin and from exposure to PFOS in sediment and surface water at the unnamed tributary to Park Creek.

PFOS concentrations across Biddle ANGB in the shallow groundwater zone measured during 2021.



Geological cross-section representing a slice through the ground surface beneath Biddle ANGB.

Groundwater Flow Model at Biddle Air National Guard Base

PROJECT GOALS AND SCOPE

The primary goal of the groundwater flow model is to simulate groundwater flow at Biddle ANGB to serve as a tool to assess potential impacts of local groundwater extraction and to conceptualize flow paths under various pumping scenarios.

The Biddle ANGB groundwater flow model (GFM) was constructed based on data from a regional groundwater flow model created by the U.S. Geological Survey (Goode and Senior 2020) and site-specific data from field studies by Leidos and others. The flow model was used to:

- Replicate groundwater conditions observed during Pilot Testing Activities
- Simulate groundwater conditions for alternate Pumping scenarios
- Visualize groundwater flow using particle tracking to assess hydraulic capture zones for groundwater extraction and treatment system design
- Perform modeling simulations from 1970 to 2022 to determine how various pumping schedules have altered the groundwater flow patterns at Biddle ANGB

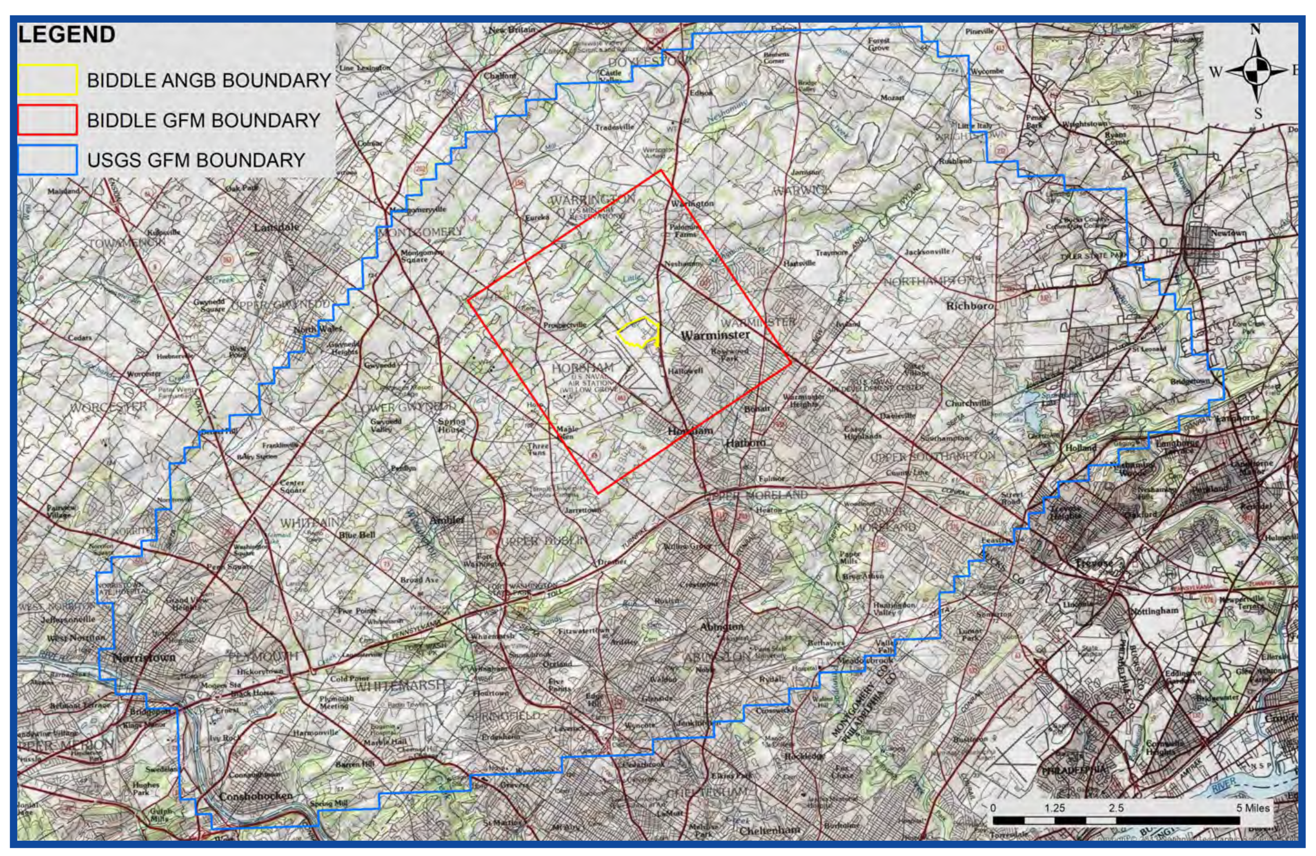


Figure showing location of Biddle ANGB GFM boundary (red box) in relation to USGS GFM boundary (blue polygon) and Biddle ANGB boundary (yellow).

GROUNDWATER FLOW MODEL CALIBRATION

GFM calibration was completed by adjusting model parameters to reduce the difference between observed groundwater level data and simulated groundwater level data. Calibration was performed with Parameter Estimation (PEST) software. As shown in the calibration plot, observed groundwater level data are compared 1:1 with modeled head elevations calculated by the groundwater model. In a well calibrated GFM, the values plot along a straight line when graphed.

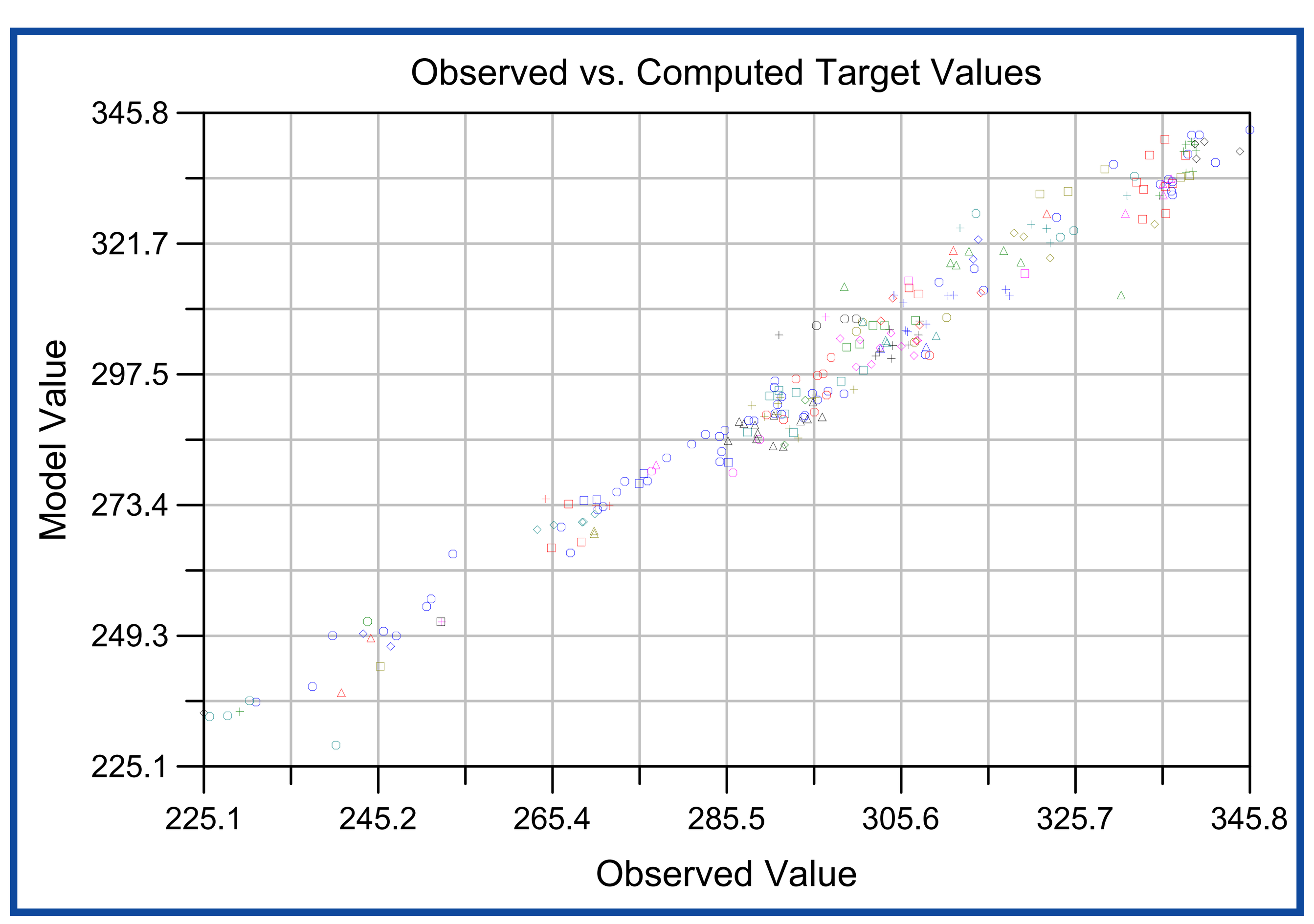


Figure showing observed vs. calculated head elevations along a 1:1 line.

GROUNDWATER FLOW MODEL CONSTRUCTION

A groundwater flow model (mathematical description) is a mathematical model that simulates the movement of groundwater and is typically translated from a conceptual site model (physical description). The Biddle ANGB GFM was created with the Groundwater Vistas graphical user interface and the USGS MODFLOW-USG modeling code to simulate groundwater flow and MODPATH-3DU was used to simulate particle tracks for travel time and flow direction analyses.

The Biddle ANGB GFM consists of 67 model layers that simulate geologic local units including the middle arkosic member and upper shale member of the Stockton formation and the Lockatong formation. The GFM extends from the ground surface to a constant depth of 500 ft below sea level. The top three model layers simulate the heavily fractured and weathered upper portions of the aquifer system and are set to constant thicknesses oriented horizontally. The remaining layers simulate the local fractured bedrock and are inclined based on an average geologic dip of 12°. The model grid is rotated to match a geologic strike of N56E in order to align groundwater flow in the x-direction with geologic strike.

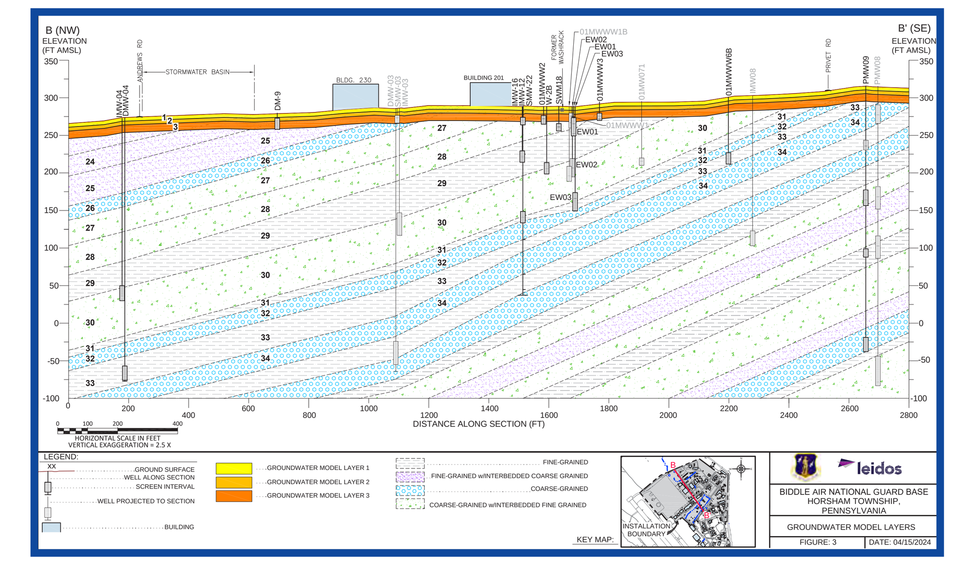


Figure showing model layer setup for vertical delineation of the model grid.

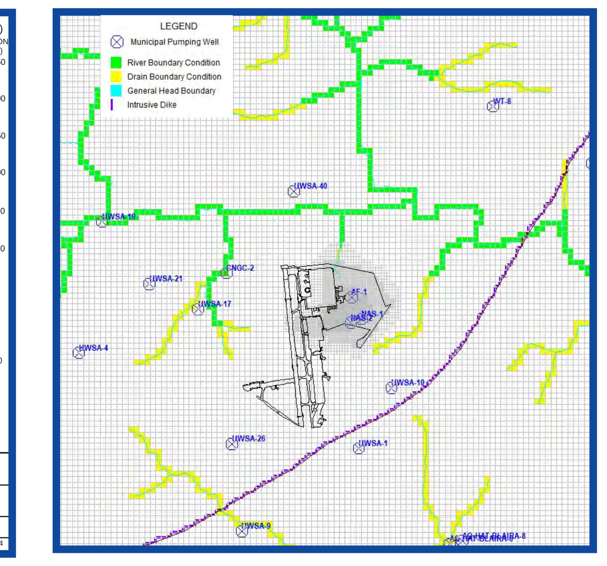


Figure showing model grid map view in Groundwater Vistas

GROUNDWATER FLOW MODEL RESULTS

The GFM was used to evaluate different pumping scenarios that would produce a desired hydraulic containment area near Building 201. Analysis showed that existing extraction wells provided capture for the area immediately around Building 201. The GFM was then used to optimize the capture zone. GFM simulations showed that adding three additional wells produces optimal containment and effectively captures a wider area.

Figure showing location of existing extraction wells in pilot test and backward particle tracking to show upgradient capture zone.

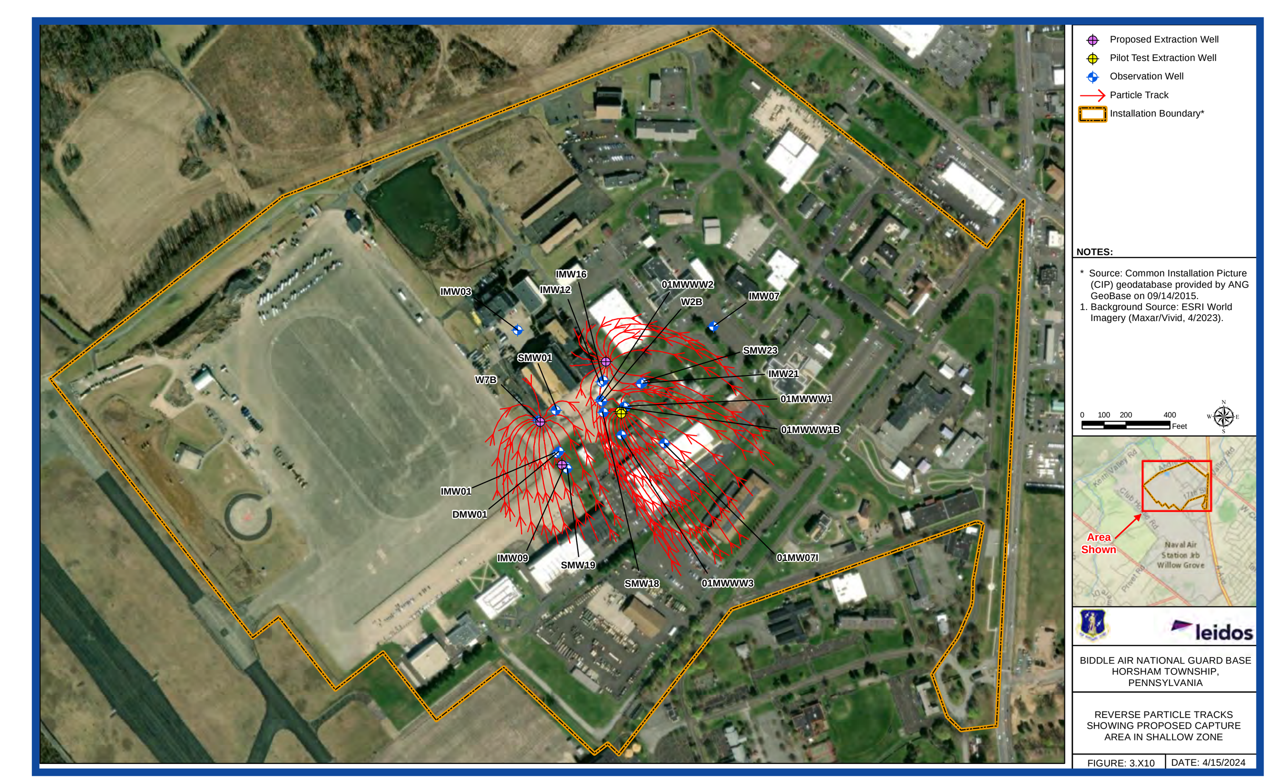


Figure showing location of existing extraction wells in pilot test plus three additional extraction wells and backward particle tracking to show upgradient capture zone.

The GFM was also used to examine groundwater elevation changes in relation to differing pumping stresses from Base supply wells. Modeling indicated that groundwater in the Intermediate Zone 2 flowed to NAS1 and NAS2 supply wells and to a lesser degree AF-1 from 1970 to 1979. But between 1980 and 1987, AF-1 was the only well operated. This changed the cone of depression to the center of the base and away from the NAS supply wells. In late 1987, the NAS supply wells were turned back on and AF-1 pumping was discontinued. These potentiometric surfaces reveal clues to how differing pumping schedules affected groundwater flow over time.

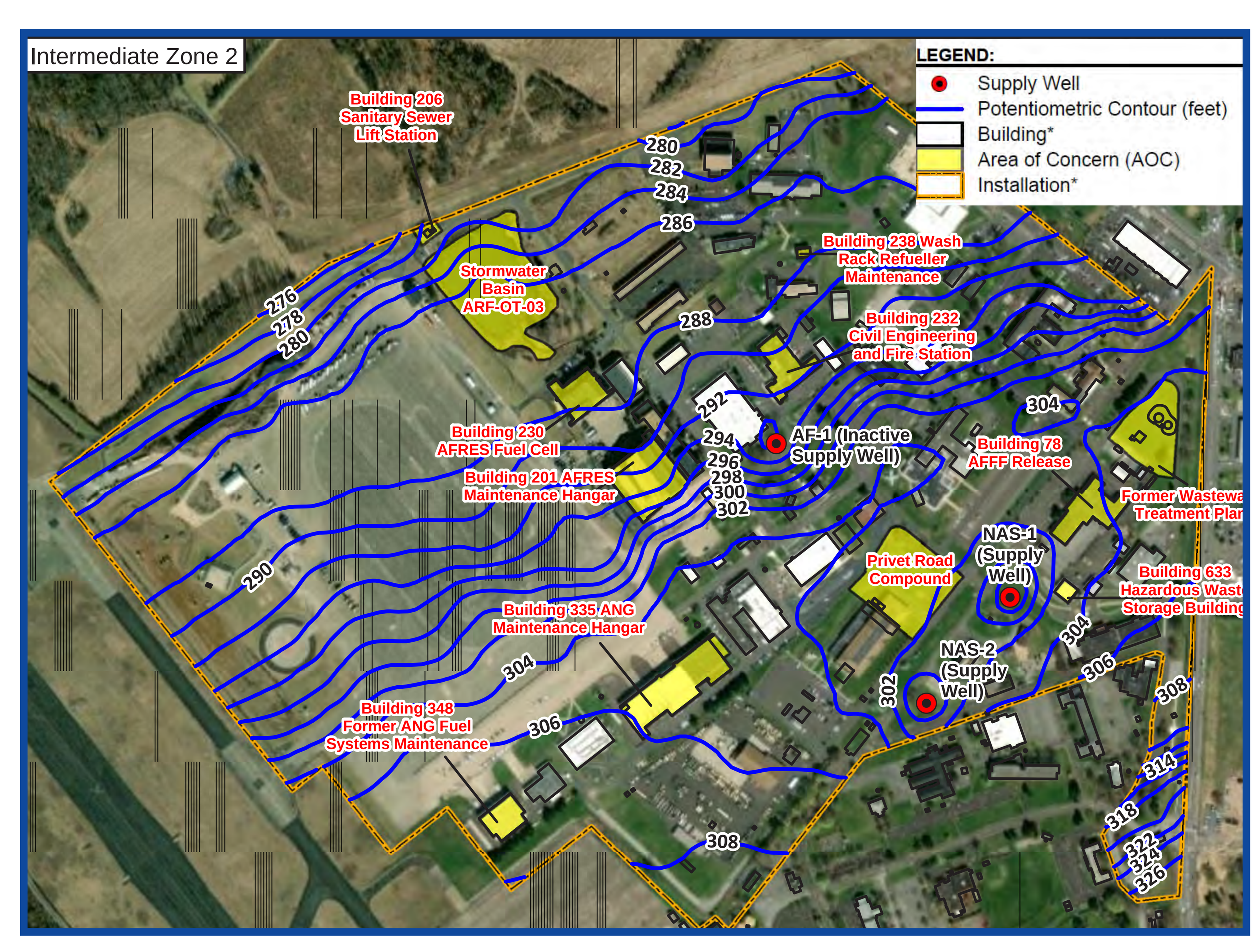


Figure showing deep Intermediate Zone 2 as simulated under 1979 pumping conditions.

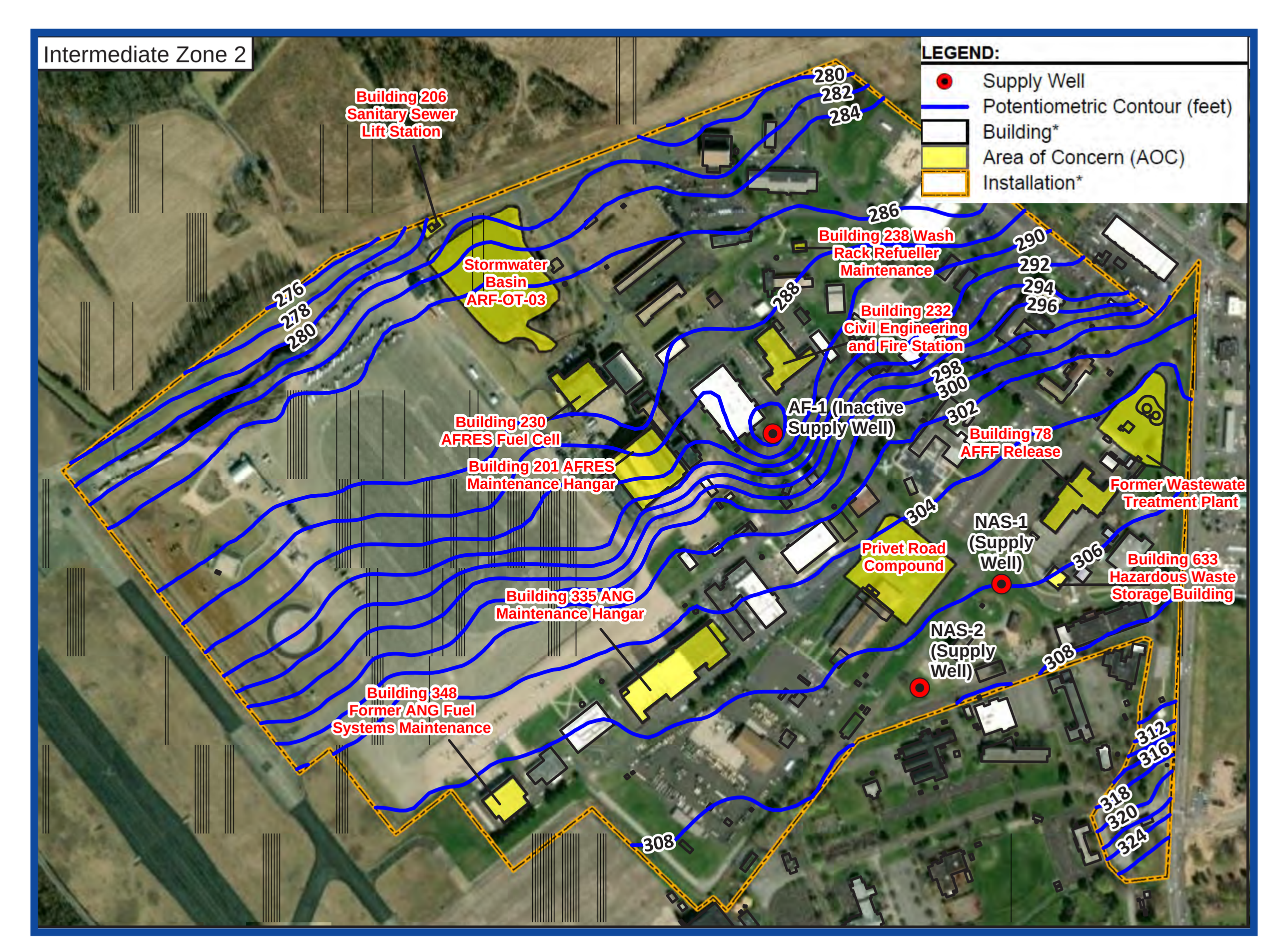
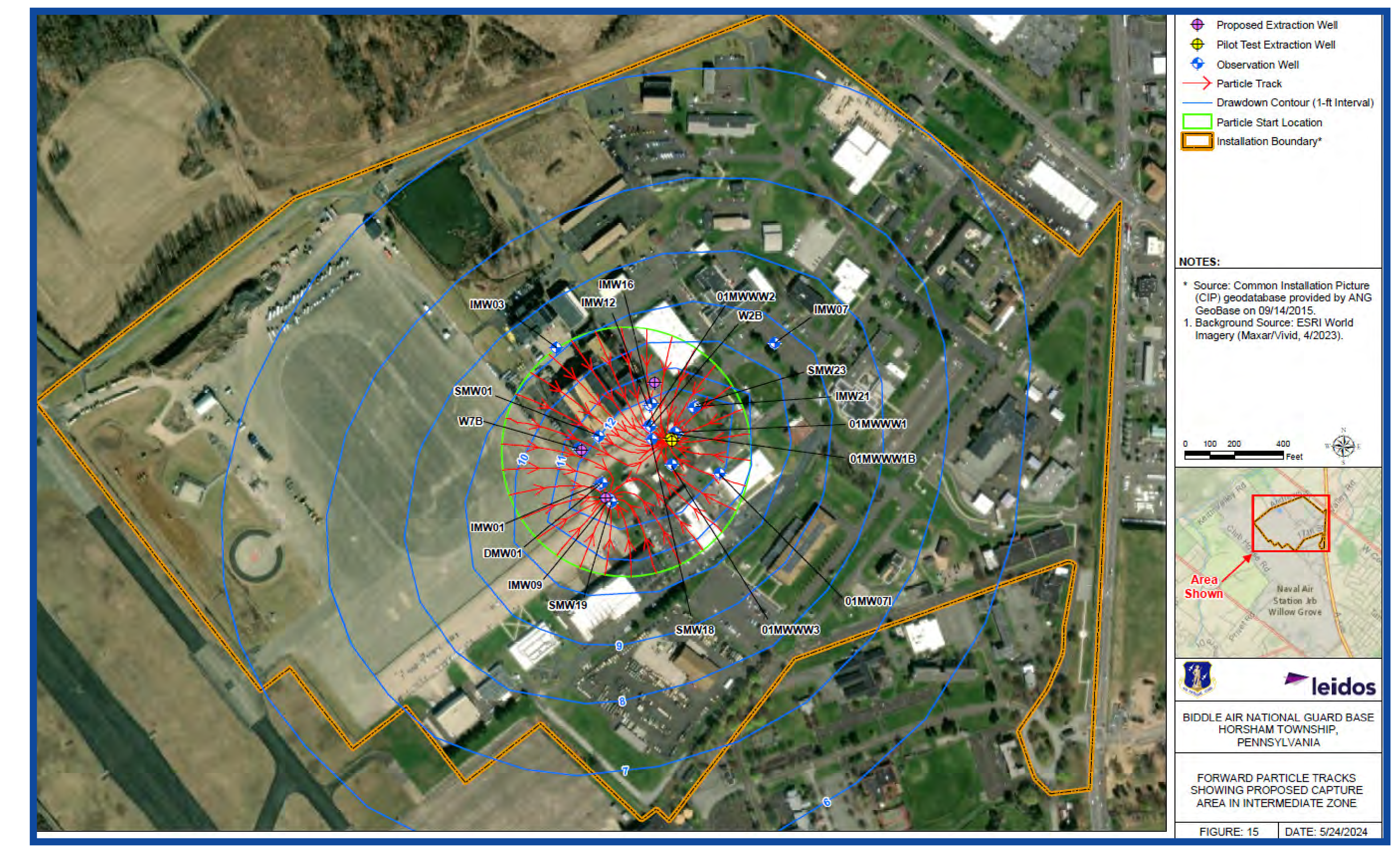


Figure showing deep Intermediate Zone 2 as simulated under 1987 pumping conditions.

Interim Groundwater Action Pilot Study at Biddle Air National Guard Base



PROJECT GOALS AND SCOPE

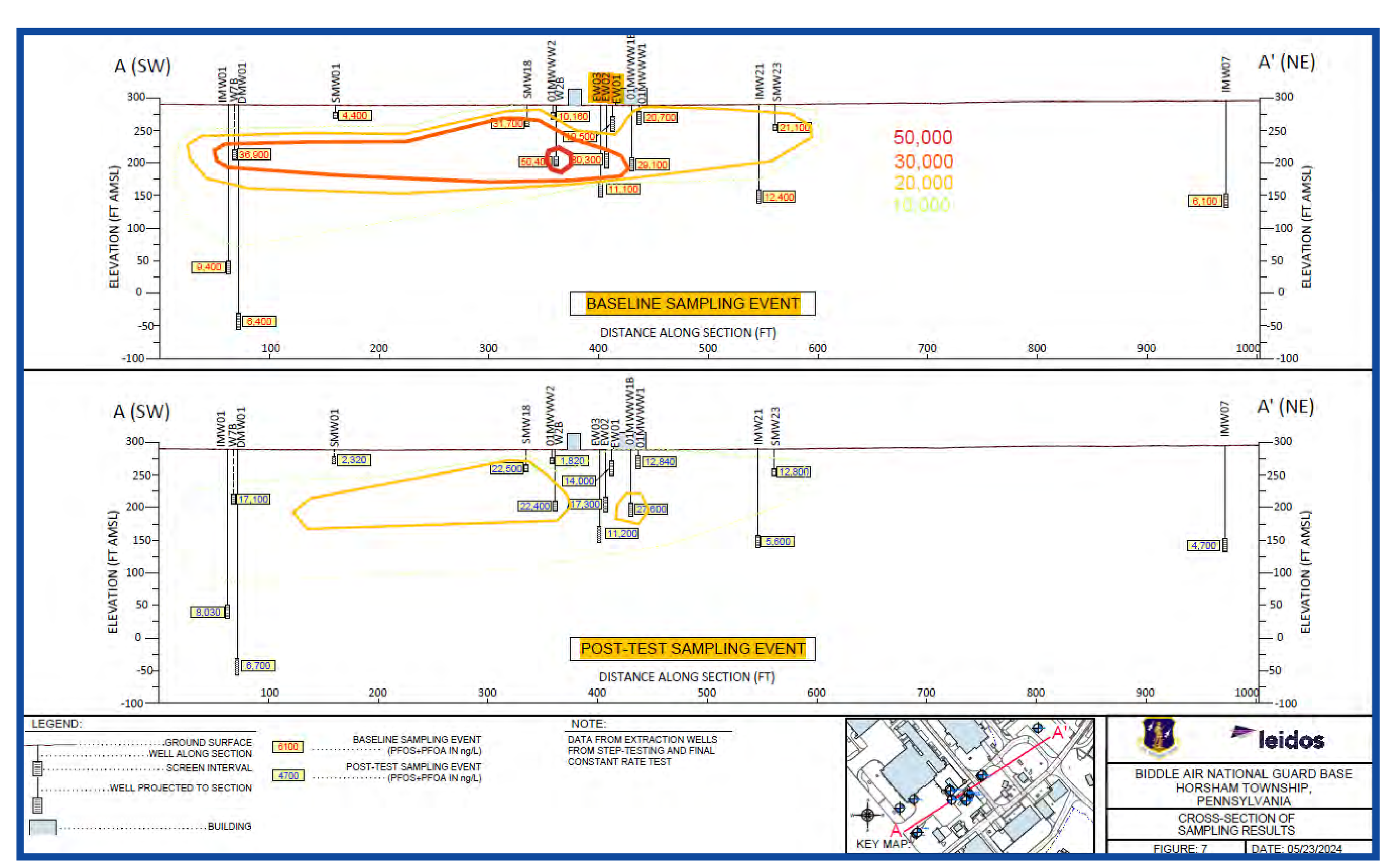
The Pilot Study was designed to collect data necessary to design, build, and operate an interim groundwater extraction system to limit the migration of PFAS contamination near Building 201 and the adjacent wash rack area (Figure 1, above). The scope and methodology for Pilot Study were developed in collaboration with the U.S. Environmental Protection Agency (EPA) and the Pennsylvania Department of Environmental Protection (PADEP) through a series of technical meetings. The goals/objectives of the Pilot Test include the following:

- **Collect hydraulic, chemical, hydrogeologic, and engineering data to support the design of an Interim Remedial Action (IRA) hydraulic containment system to address the suspected PFAS source area near Building 201 and the adjacent wash rack area**
- **Conduct a 30-day Pilot Test using a series of three extraction wells (EWs) screened within the shallow and intermediate-depth bedrock aquifer zones**
- **Avoid capturing PFAS-impacted groundwater from upgradient or off-site sources**
- **Avoid pulling PFAS-impacted groundwater from shallow aquifer zones to deeper aquifer zones**
- **Avoid impacting the operation of Biddle ANGB supply wells (NAS1 and NAS2) or ongoing groundwater extraction operations at the adjacent former Naval Air Station Joint Reserve Base (NAS JRB) Willow Grove**

The Pilot Testing scope of work included:

- **Withdrawal and discharge permitting**
- **Installation of three EWs and two monitoring wells (MWs)**
- **Baseline and post-test groundwater sampling and analysis**
- **Automated potentiometric gauging before, during, and after Pilot Testing**
- **Design, construction, and operation of a temporary groundwater extraction and treatment system**
- **Conducting a 30-day groundwater extraction Pilot Test including step-drawdown testing and constant-rate pump testing-**

Pilot Test Extraction and Treatment System Process



PILOT TEST RESULTS

Pilot Study results indicated that the selected treatment media (GAC and SORBIX™ Resin) are suitable for the IRA. Pilot Study data did not indicate the need for pretreatment; other than sediment filtration like that used for the Pilot Test.

The Pilot Study recommended a potential IRA with three (3) additional extraction wells and a treatment system designed for at least 85 gpm and approximately 45,000 nanograms per litre (ng/l) PFAS. Based on Pilot Study results the proposed IRA could use a similar treatment system design but with added redundancy.

SUMMARY

All project goals were achieved and showed that the PFAS-impacted groundwater can be effectively captured, removed, and treated in accordance with the Base NPDES discharge requirements.

ER23-8381: Surface Active Foam Fractionation for PFAS Treatment

Dr. Kent Sorenson
Dr. Jason Hnatko
Zach Pierce
Zach Foudeh

Abstract/Overview

This project will demonstrate Surface-Active Foam Fractionation (SAFF®) to remove PFAS from contaminated water and highlight SAFF's capabilities and utility as a commercial, off-the-shelf PFAS removal technology. The site selected for the field demonstration is Biddle Air National Guard Base, located in Horsham Township, Pennsylvania (Biddle ANGB).

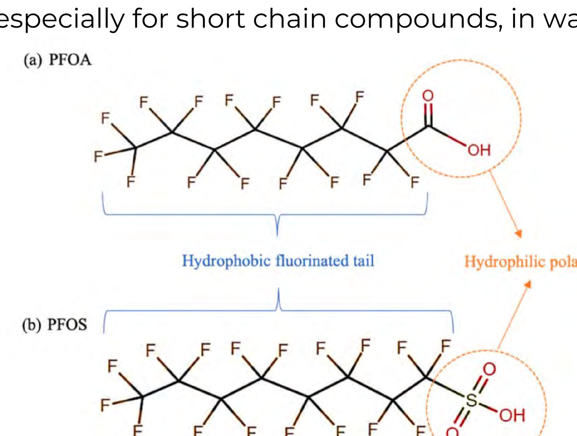
This PFAS impacted water treatment demonstration utilizes Allonnia's SAFF mobile water treatment plant. Through foam fractionation, gas (ambient air in the case of SAFF) is bubbled through a container of PFAS-contaminated water, adsorb the PFAS to the surface of rising bubbles due to their surfactant-like properties, forming a froth/foam layer above the liquid surface. This foam layer is then separated and collapsed to form a "foamate" liquid enriched in PFAS. The bulk liquid in the remainder of the fractionation vessel is depleted of PFAS. Essentially, air bubbles act as an adsorbent in much the same way as granular activated carbon (GAC) does for other applications, but with the advantage that air bubbles are cheap, mobile, require no resources for manufacture and transport, and do not require disposal after use.

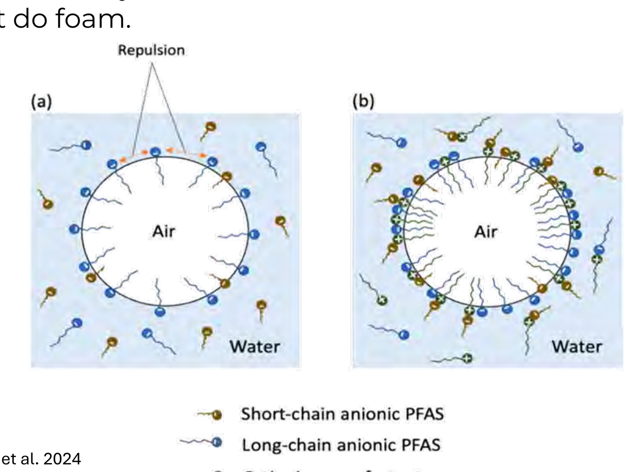
The objective of this work is to demonstrate and validate that SAFF is a year-round, safe, cost-effective, and sustainable means to help improve the United States of America's water security. SAFF is available now and manufactured as a commercial off-the-shelf technology, with growing adoption among commercial and government entities.

Principles of Foam Fractionation

Foam fractionation utilizes the amphiphilic nature of PFAS to separate them from water using rising air bubbles.

- PFAS have a hydrophilic head that prefers to be in a water phase and a hydrophobic tail that prefers to be away from water in an air phase
- Because of these properties, PFAS accumulate at air-water interfaces
- SAFF creates small bubbles with a high surface area of air-water interfaces that accumulate PFAS
- As these bubbles rise through a water column, PFAS move to the top and are collected in a foam or aqueous solutions that is separated as a "foamate" or "PFAS concentrate"
- At the end of the process, PFAS has been removed from the remaining water which is discharged as clean effluent.
- For waters that do not naturally foam, additives may be introduced during the fractionation process to enable better PFAS removal. Certain additives may also enhance PFAS removal, especially for short chain compounds, in waters that do foam.





Images from We et al. 2024

Site Conditions/Layout

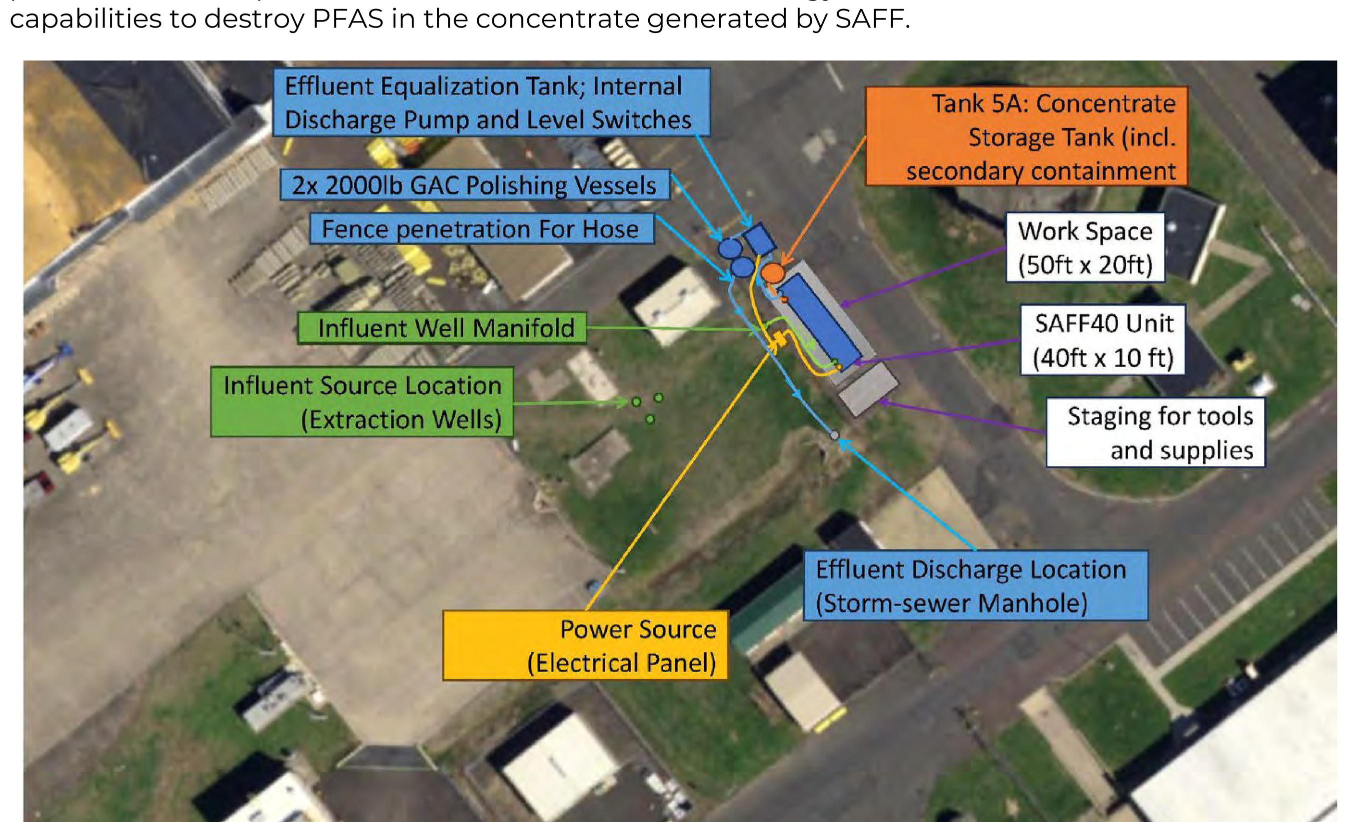
Three existing, PFAS-impacted groundwater extraction wells were selected as SAFF influent. These wells are connected to a manifold where the source water is mixed before entering the SAFF.

Electricity is provided from a temporary panel installed by the base near the SAFF.

Treated water is discharged to a storm-sewer manhole that leads to the base's existing stormwater treatment system.

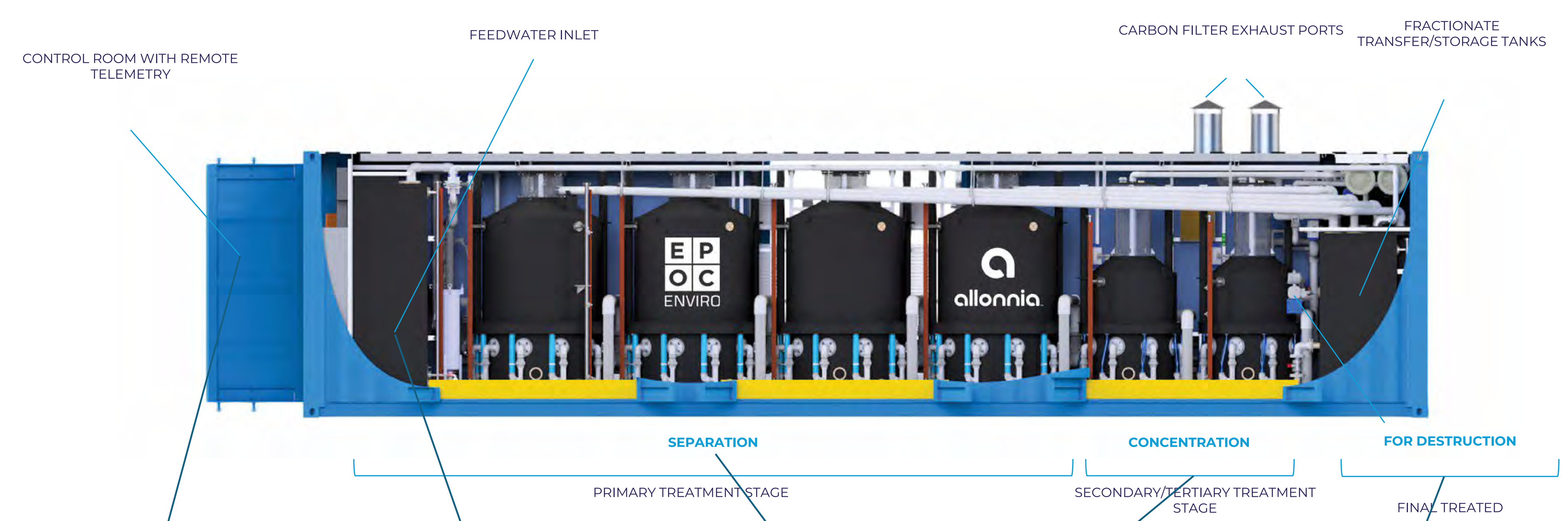
In addition to the SAFF, Allonnia provided an effluent equalization tank and two granular activated carbon (GAC) vessels to provide additional treatment for PFAS removal after SAFF treatment. This was included to provide additional certainty that concentrations would be below discharge criteria for continuous operations.

PFAS concentrate generated from tertiary fractionation is accumulated on site in 250-gallon plastic totes to be provided to various destruction technology vendors for demonstration of their capabilities to destroy PFAS in the concentrate generated by SAFF.



Allonnia's SAFF40 Containerized Treatment System

Allonnia, in cooperation with EPOC Enviro, deploys foam fractionation for PFAS removal as a fully containerized, mobile treatment plant. The unit contains everything needed to remove PFAS through foam fractionation including tanks, controls, and pumps.



Remote telemetry for monitoring. The SAFF includes a human machine interface (HMI) for on-site operations and adjustments and remote telemetry for off-site monitoring and operational adjustment. Sensors and alarms trigger messages that are sent to operators, allowing unmanned operation 24/7.

SAFF operates as a semi-batch process. Feed water is continuously introduced and stored in an internal tank. The system automatically distributes this influent to primary fractionation batches to run a pre-programmed fractionation cycle.

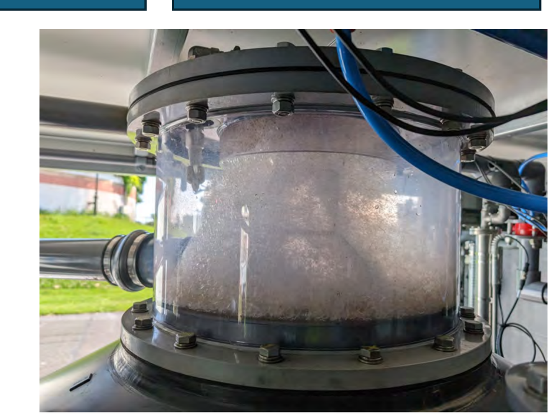
PFAS are removed in the primary treatment stage. Four primary separation vessels operate in parallel to remove PFAS from influent water. Air is introduced at the bottom of the vessel to create a PFAS enriched concentrate and treated effluent.

Secondary and tertiary treatment reduce waste volumes. Two secondary treatment vessels operate in parallel or series (tertiary treatment) to further concentrate PFAS from the primary PFAS concentrate into a secondary (or tertiary) concentrate.

All necessary storage tanks are included in the unit. Treated water and primary, secondary, and tertiary PFAS concentrate are stored in internal tanks. Treated water can be discharged directly after each batch or sent to downstream treatment. Concentrate is suitable for on- or off-site destruction using a variety of technologies.

All necessary equipment included in containerized system

Primary separation removes PFAS



PFAS accumulate in concentrate at the top of the vessel

Secondary fractionation reduces waste volume

Concentration of PFAS Using Multi-stage Foam Fractionation

SAFF utilizes multiple stages of foam fractionation to drastically reduce waste volumes allowing for cost-effective and environmentally sustainable destruction of PFAS.

~10 gallons of concentrate produced after treating 1,000,000 gallons

Primary Fractionation (5-20x concentration) → Secondary Concentration (100-1000x concentration) → Tertiary Concentration (50-200x concentration)

Concentration factors are multiplicative across fractionation stages

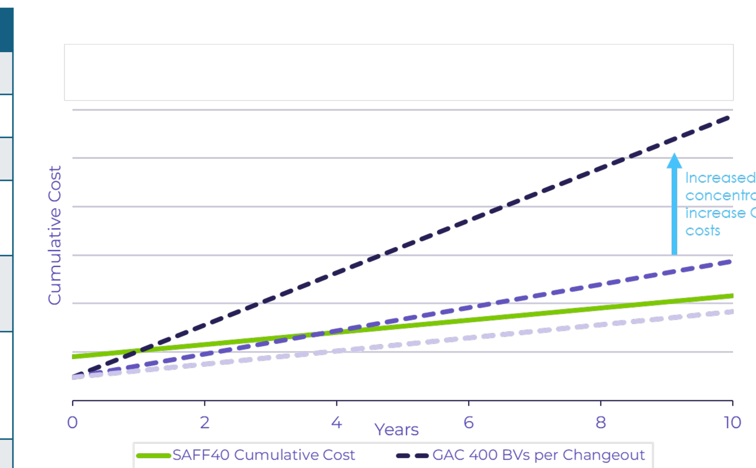
Concentration factor and foam generation is highly dependent on water type and treatment objectives. Primary and secondary treatment provides concentration factors ranging from:

- 500 to 2000X for Landfill Leachate
- 2,000 to 100,000X for Non-Foaming Groundwater
- 10,000 to 100,000X for RO Reject
- 1,000 to 100,000X for Surface Water

Including tertiary treatment provides an additional 100 to 1000X concentration factor

Benefits of SAFF Treatment vs. Conventional Treatment[1]

	Conventional Treatment[1]	Foam Fractionation
Spent media volume	High	None
Waste generated	High	Very low
Pretreatment required	High	None
High concentration removal efficiency	Inefficient	No impact
Cost	High cost per mass of contaminant removed	Lowest OPEX, lower lifetime costs but higher CAPEX
Influent concentration effect on cost	Higher costs at higher influent concentration	Cost not impacted by influent (effective from 0.005 to >50,000 ppb)
Sustainability performance	Low	High
Remote telemetry capabilities	None	Fully automated



[1]Conventional treatments are granular activated carbon and ion exchange adsorptive technologies

Performance Objectives

Demonstration of effective PFAS separation and concentration by SAFF over a 6-month operating period in a range of seasonal conditions (e.g., temperature) and achievement of EPA Maximum Contaminant Levels (MCLs) using post-SAFF polishing.

- Enhance PFAS short chain removal using foaming additives (boosters)
- Evaluate the potential for enhanced PFAS removal via electrolyte addition
- Demonstration of hyper-concentration of PFAS using three stages of foam fractionation.
- Validation of system controls on airborne (i.e., volatile or aerosolized) PFAS, if any.

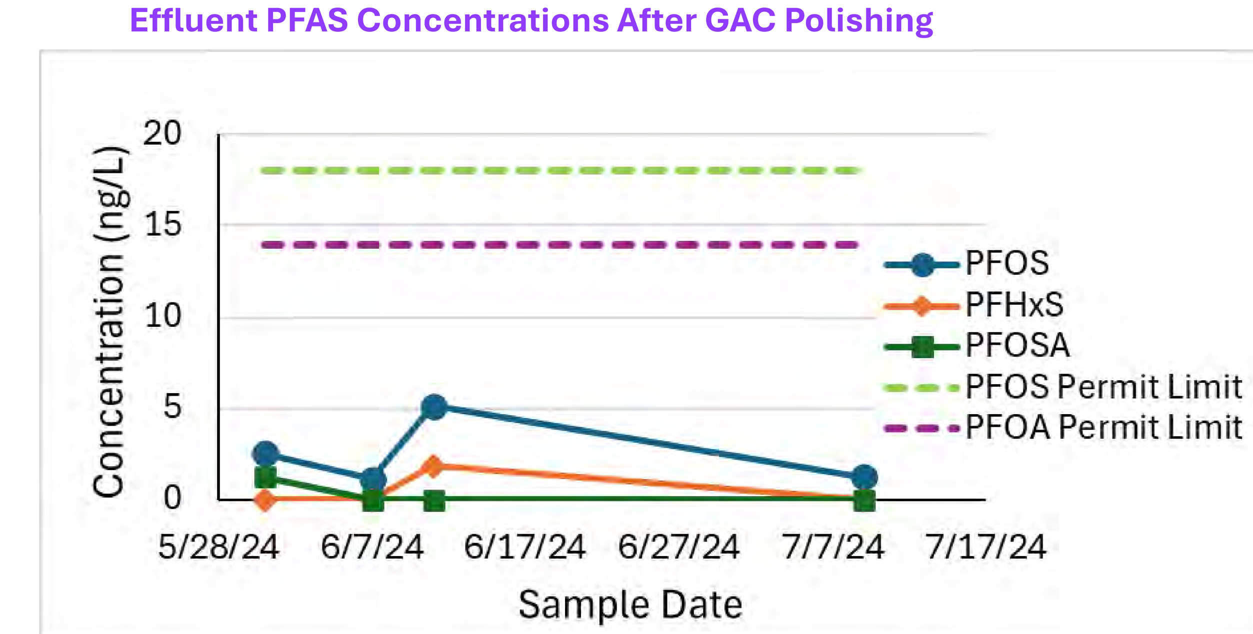
Results to Date

>2.64 Million Gallons Treated

<30 gallons of tertiary concentrate produced

Analyte	Influent Concentration (ng/L)	SAFF Effluent Concentration (ng/L)	Percent Removal	Post-GAC Effluent Concentration (ng/L)
PFBA	243	215	11.5%	<1.47
PFHxA	993	786	20.8%	<0.737
PFHpA	232	77.8	66.5%	<0.737
PFOA	812	4.71	99.4%	<0.737
PFNA	13	<0.755	100%	<0.737
HFPO-DA	<3.27	<1.51	NA	<1.47
PFBS	695	573	17.6%	<0.737
PFHxS	2894	182	93.7%	<0.737
PFOS	9414	9.12	99.9%	1.24
6:2 FTS	786	5.07	99.4%	<1.47
8:2 FTS	67.8	<1.51	NA	<1.47
Total PFAS	**16153**	**1856**	**67.6%**	**<11.5**

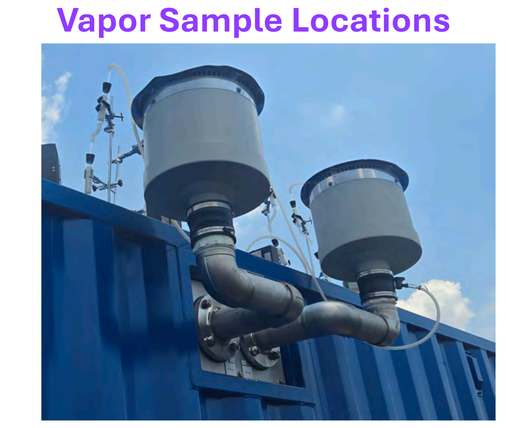
Effluent PFAS Concentrations After GAC Polishing

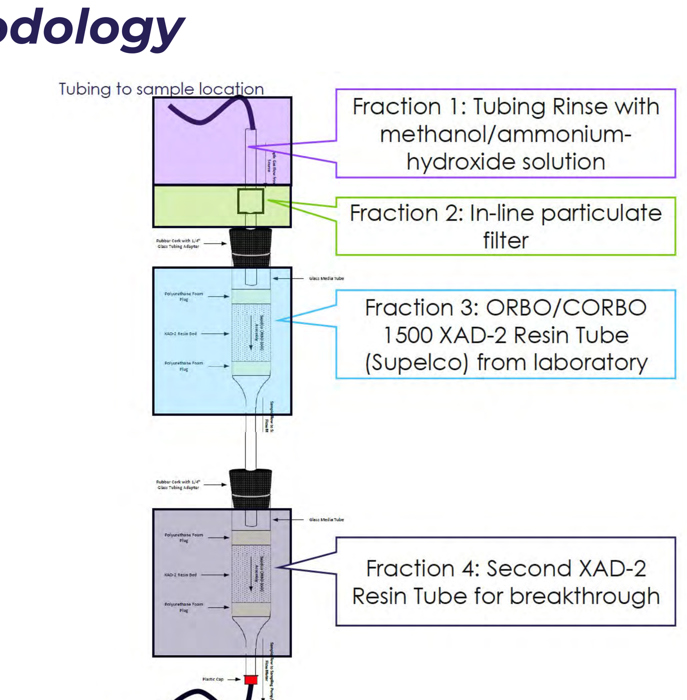


All other PFAS concentrations were below laboratory reporting limits in post-GAC samples
PFOS and PFOA limits established by PADEP permit

Vapor Sampling Methodology

Vapor Sample Locations





- OTM-45 is not practical for small diameter piping and GAC exhaust
- Modified from USEPA Method TO-13 (PAHs in ambient air) in collaboration with Eurofins
- Addition of tubing rinse, filter, and second resin tube for aerosol collection
- Separate fractions to be analyzed, similar to OTM-45
- Laboratory analytical methods, analytes, and reporting limits identical to OTM-45

Off-Base Drinking Water Sampling & Mitigation - Biddle Air National Guard Base

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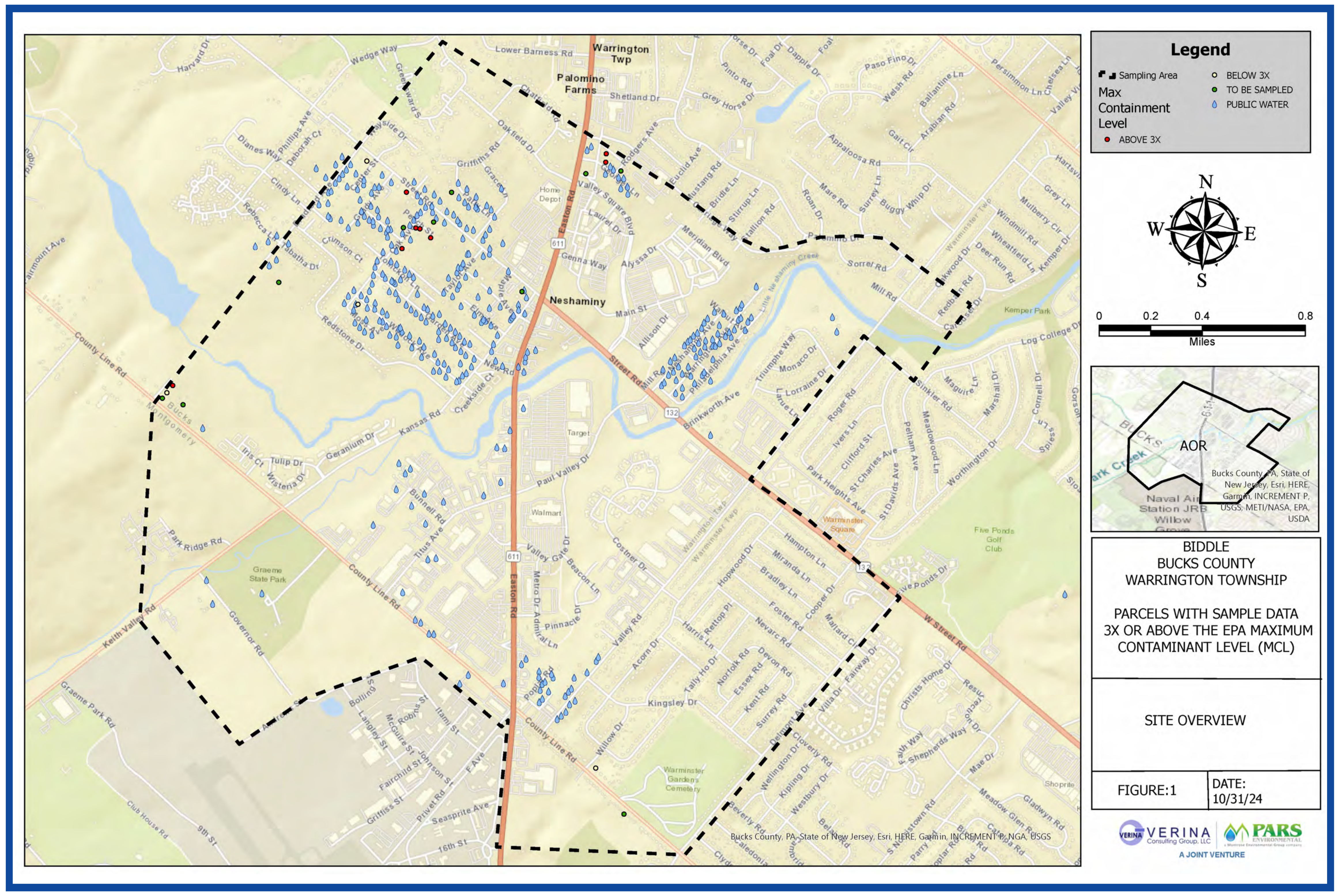

PFAS Standards Timeline 2016 to present

PFAS guidelines, policies and regulations first took effect in the early 2000s. USEPA released Lifetime Health Advisory (HA) Limits for PFOS and PFOA in 2016 and advised municipalities to make consumers aware of PFAS levels that exceeded those limits. States began implementing policies to prevent PFAS pollution and protect consumers from exposure - PADEP released MCLs in January 2023. In April 2024 USEPA assigned enforceable maximum contaminant levels (MCL) for five PFAS under the Safe Drinking Water Act (SDWA): perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorononanoic acid (PFNA), hexafluoropropylene oxide dimer acid (HFPO-DA, aka GenX), and perfluorohexane sulfonic acid (PFHxS). Rule gives regulated public water systems five years to comply. DoD implementation prioritizes private drinking water wells and affected receptors exceeding 3x the USEPA MCL, and has addressed 55 where the HA was exceeded.

PROJECT GOALS

Inventory remaining properties within the Biddle sampling boundaries (Figure 1) not connected to a municipal water supply that use private well as a water source. Verify presence/concentrations of PFAS in well water through sampling and reporting results to residents. Work with ANG and water utilities to connect those homes that exceed MCLs and DoD action limits (below) to public water source.

2016 - 2019

USEPA issued a lifetime drinking water HA level of 70 parts per trillion (ppt) for PFOS and PFOA

HA's - not enforceable standards, used to assist federal, state, tribal, and local officials protect public health where PFAS was found in DW supplies

DoD completed preliminary assessments at 710 of 717 installations and interim actions at 55 - sampling in Biddle AOR began in 2017.

14 January 2023

PADEP established rule setting MCLs for PFOS and PFOA:

PFOS: 18ppt

PFOA: 14 ppt
ANG sets action level at ½ PADEP MCL
Actions:
Below MCL: safe
Between ½ MCL and MCL: Quarterly monitoring
Above MCL: bottled water or POET. Resident eligible for municipal water connection

26 April 2024

EPA assigns enforceable MCLs for 5 PFAS:

PFOS: 4ppt

PFOA: 4 ppt

HFPO-DA: 10 ppt

PFNA: 10 ppt

PFHxS: 10 ppt

03 September 2024

DoD issues Implementation Memo designating 3x MCL as priority threshold for action:

PFOS: 12ppt

PFOA: 12 ppt

HFPO-DA: 30 ppt

PFNA: 30 ppt

PFHxS: 30 ppt

PROJECT ACTIVITIES

- Maintain updated well inventory / identify properties not connected to municipal water using private wells
- Outreach to residents and provide program information
- Sample water from kitchen tap (preferred) or hose-bib, analyze for PFAS by EPA method 537.1
- Compare results to the EPA MCL and the DoD-established 3x MCL action level & communicate results to residents
- Determine need/eligibility for alternate water supply (municipal connection (preferred); point-of-entry treatment (POET) system (whole-house treatment); bottled water (last resort)
- Support ANG Biddle to provide alternate water supply / coordinate with NWWA for municipal connection

STATUS

- ~140 homes connected to municipal water as part of ANG efforts; ~200 others connected by others
- 163 properties sampled; 37 properties actively engaged

QUESTIONS?

ANG Point of contact:

Bill Myer
Environmental Restoration Program Manager
william.myer.2@us.af.mil
Phone: (774) 994-7265

Verina-PARS Point of Contact:

Eric White
Project Manager
epwhite@montrose-env.com
phone: (609) 751-0466