Nanofiltration Followed By Electrical Discharge Plasma for Destruction of PFAS and Co-Contaminants in Groundwater: A Treatment Train Approach

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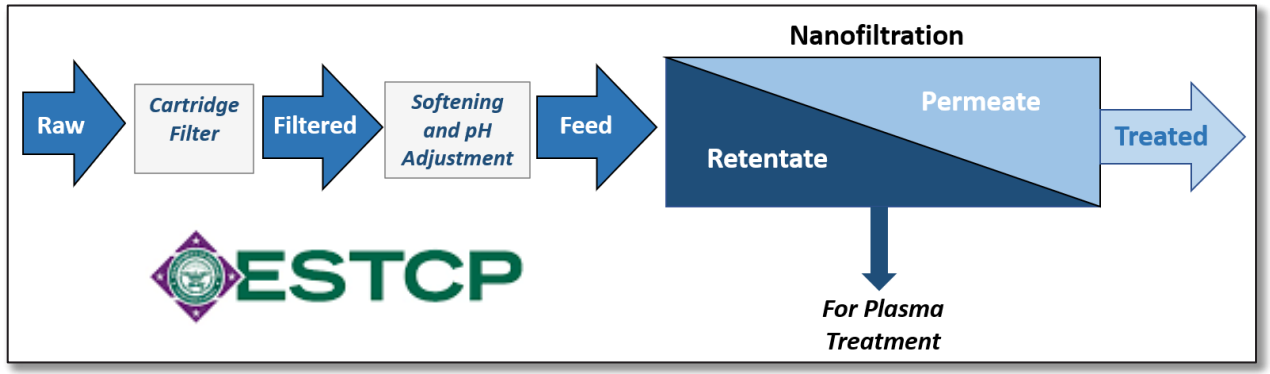
2024 International Conference on Remediation of Chlorinated and Recalcitrant Compounds



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Technical Objectives

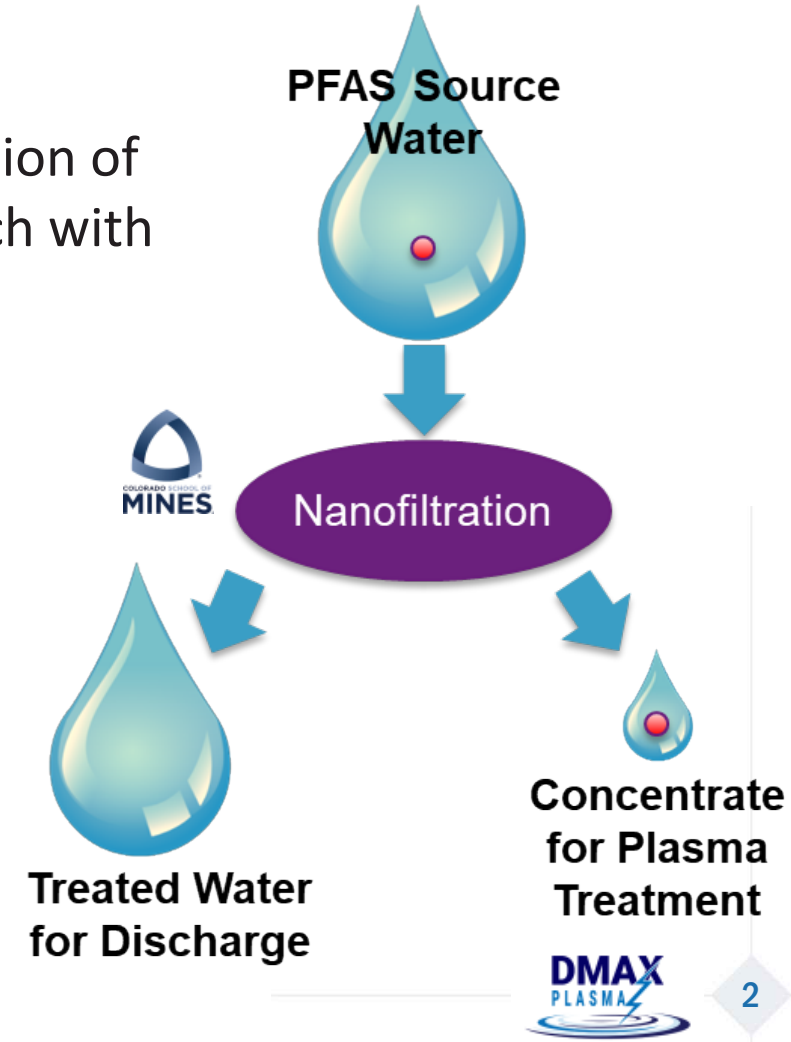
What's Needed?

- Since PFAS plumes are generally dilute (often a few ppb), remediation of PFAS-impacted water best lends itself to a treatment train approach with integrated ***PFAS concentration and destructive steps***

Our Objective

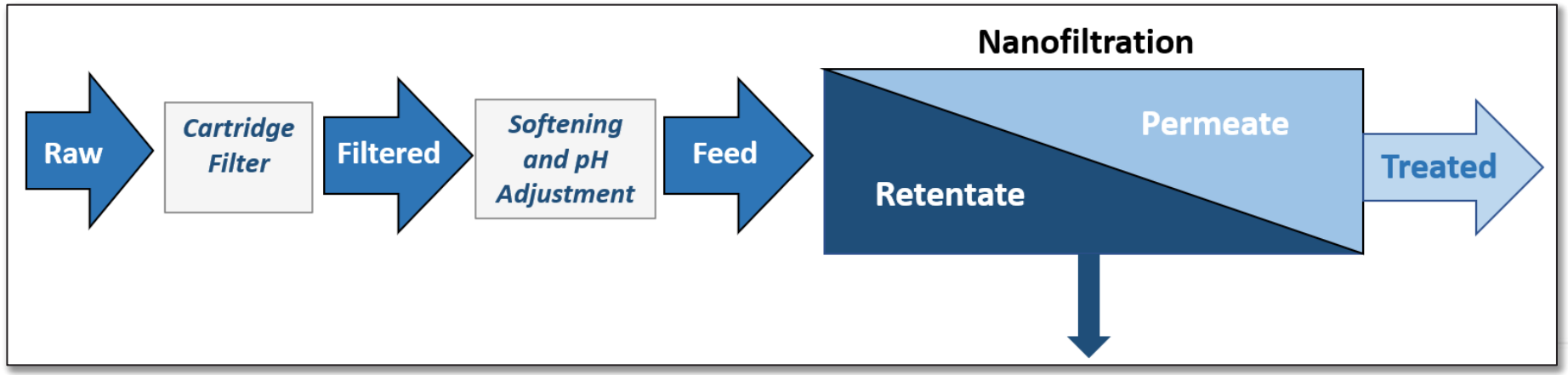
- Demonstrate and validate a field-scale integrated treatment approach:

1. ***Nanofiltration*** to concentrate PFAS and co-contaminants
2. ***Electrical Discharge Plasma*** to treat concentrate
3. "Apple to Apples" Bench-scale comparison of ***Electrochemical Oxidation and Plasma***



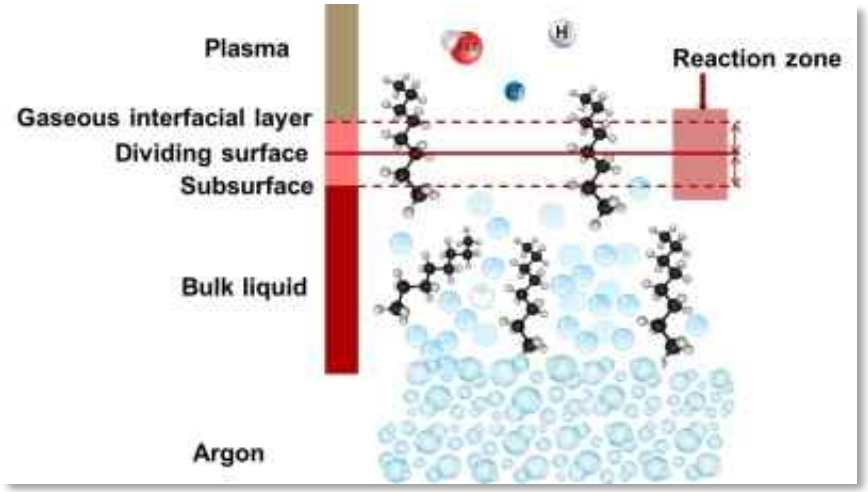
Nanofiltration: *The Basics*

- High-pressure separation process where solutes are retained by membranes and concentrated into a smaller volume of water (***retentate or concentrate***)
- Majority of feed water exits system as treated ***permeate (or filtrate)***
- ***% Recovery:*** proportion of feed water recovered as permeate
- ***% Rejection:*** proportion of solute (PFAS) retained by the membranes



Enhanced Contact Plasma:
The Basics

- Uses electricity to convert water into a mixture of highly reactive species (e.g., hydroxyl radicals, aqueous electrons)
- Rapidly and non-selectively degrade recalcitrant organic contaminants (e.g., PFAS)
- **Plasma Formation:** High voltage applied between suspended electrodes and submerged grounded electrodes
- **PFAS Destruction:** Argon gas bubbles drive PFAS to the liquid surface for interaction with plasma



Field Demonstration:
Experimental Conditions

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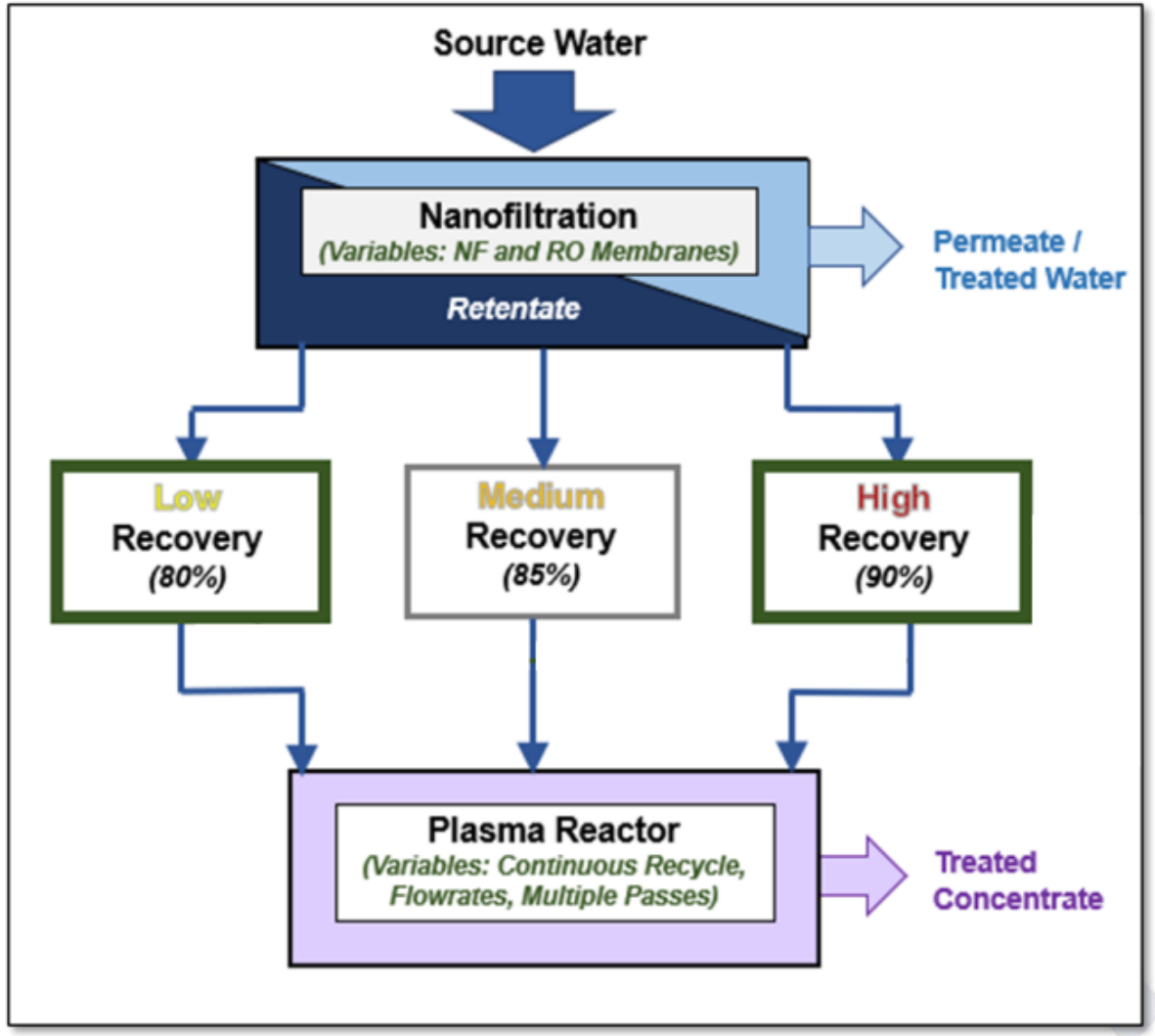
Nanofiltration

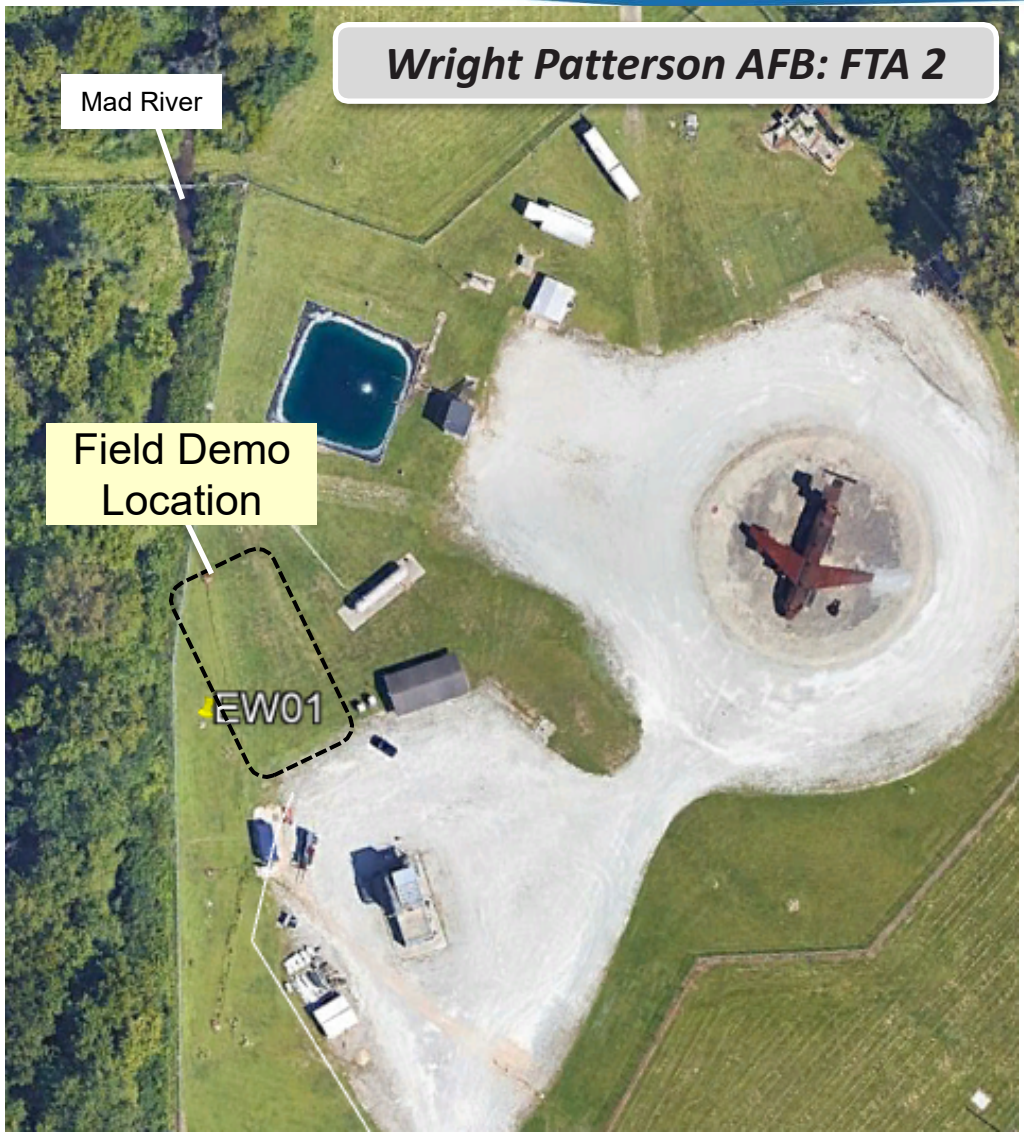
- Membranes: NF90 and CR100
- Recovery Setpoints: Low (80%), Medium (85%) and High (90%)

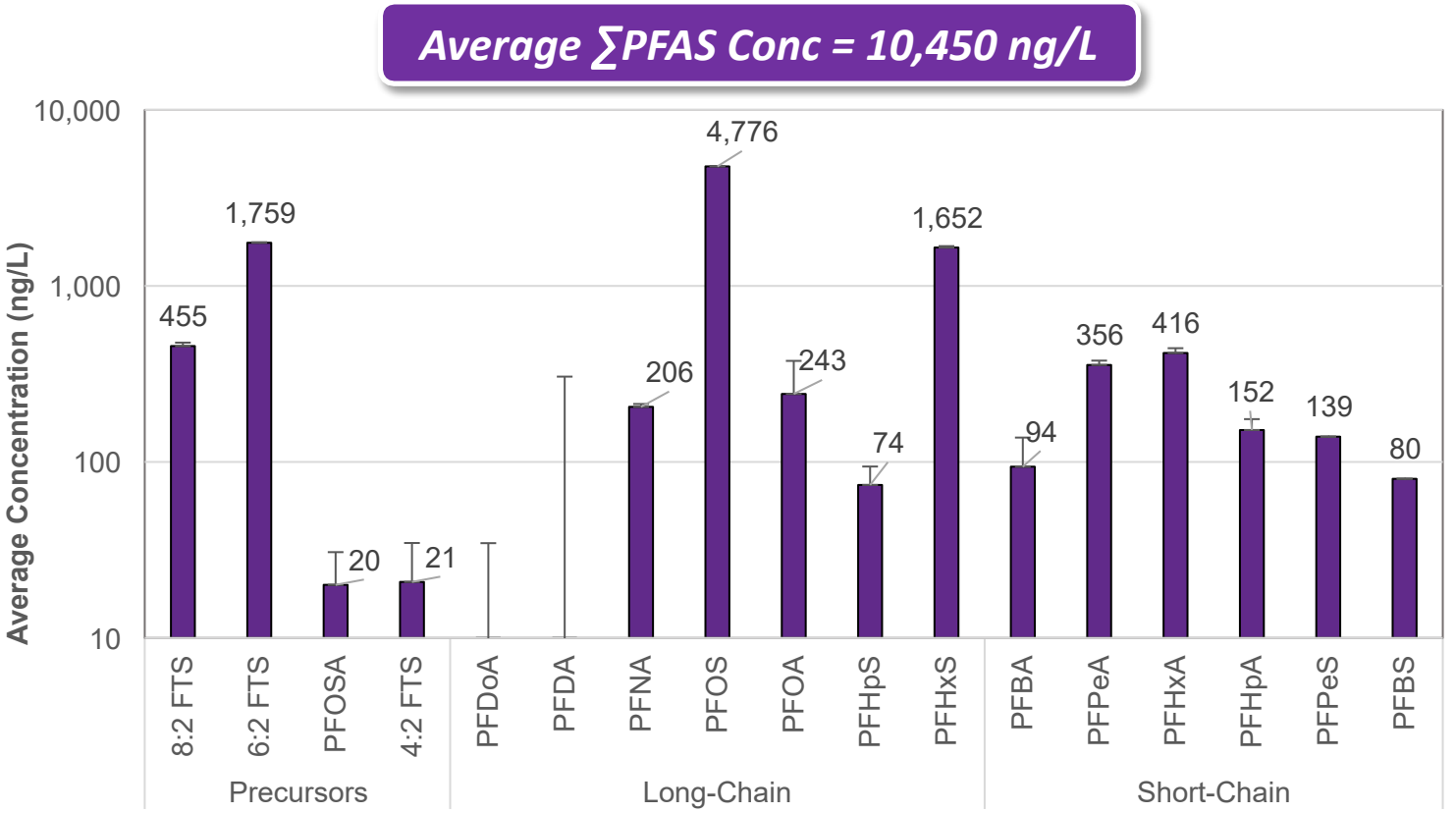
Enhanced Contact Plasma

- Mode of Operation:
  - Continuous Recycle (single reactor)
  - Flow-through (three reactors)



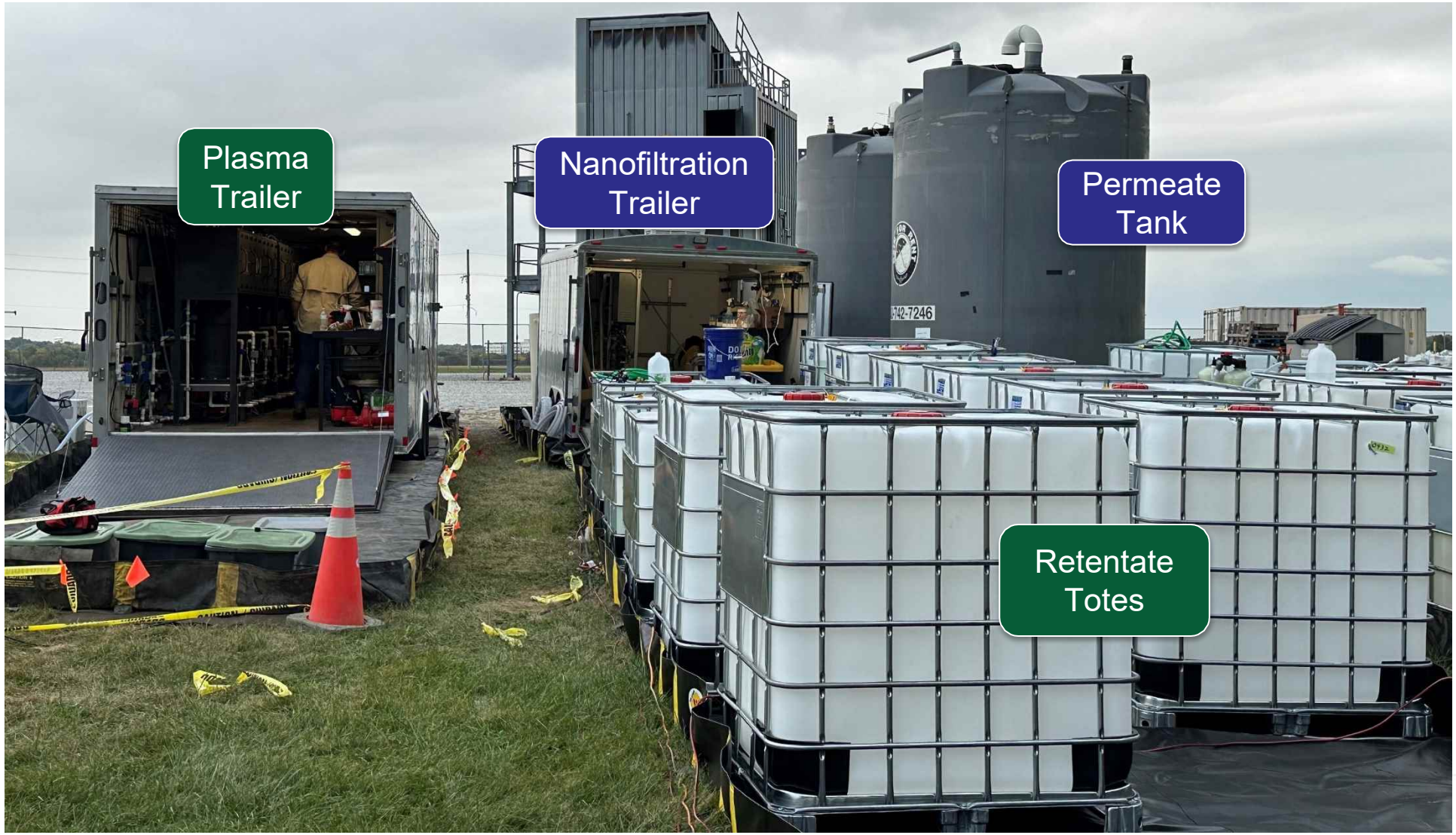
Field Demonstration: *Site Characteristics*



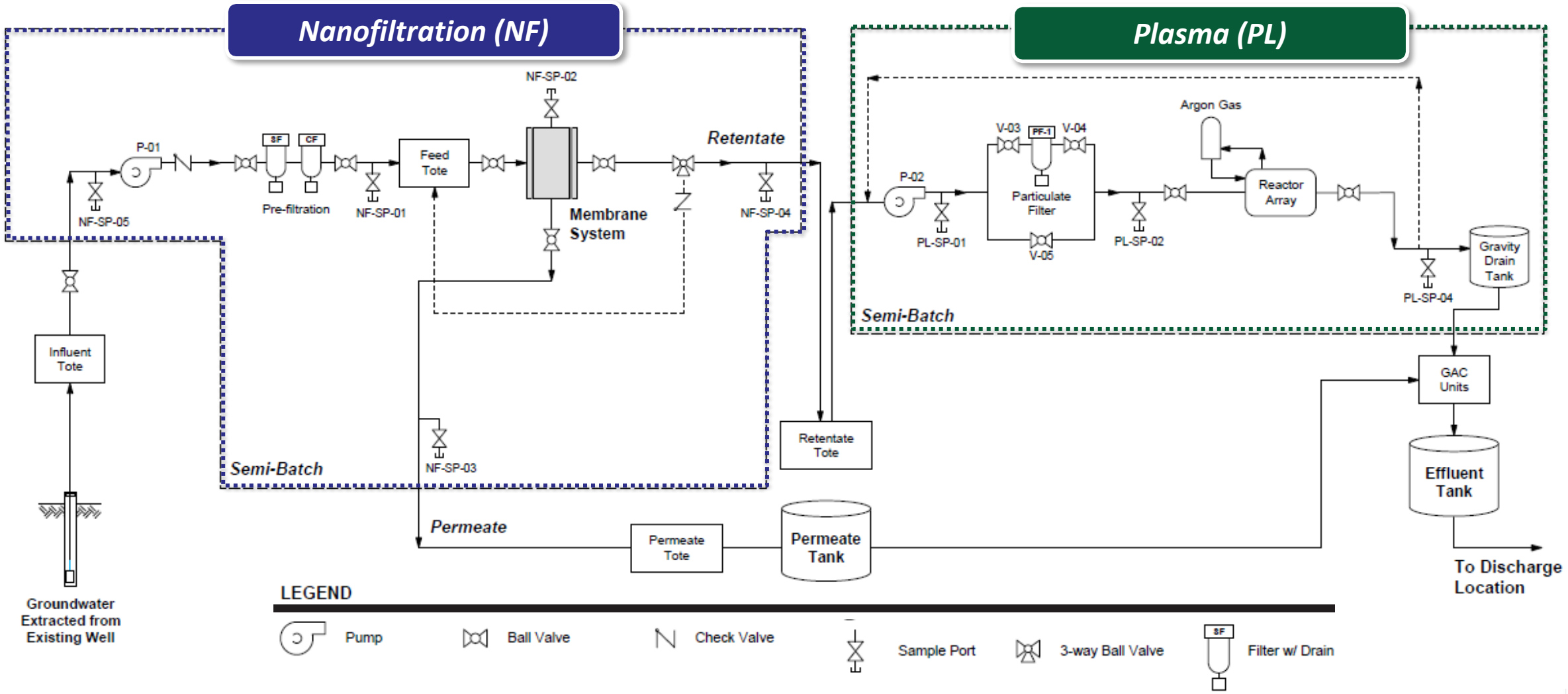


- Most abundant PFAS: PFOS, 6:2 FTS, and PFHxS
- Elevated alkalinity, calcium, and iron

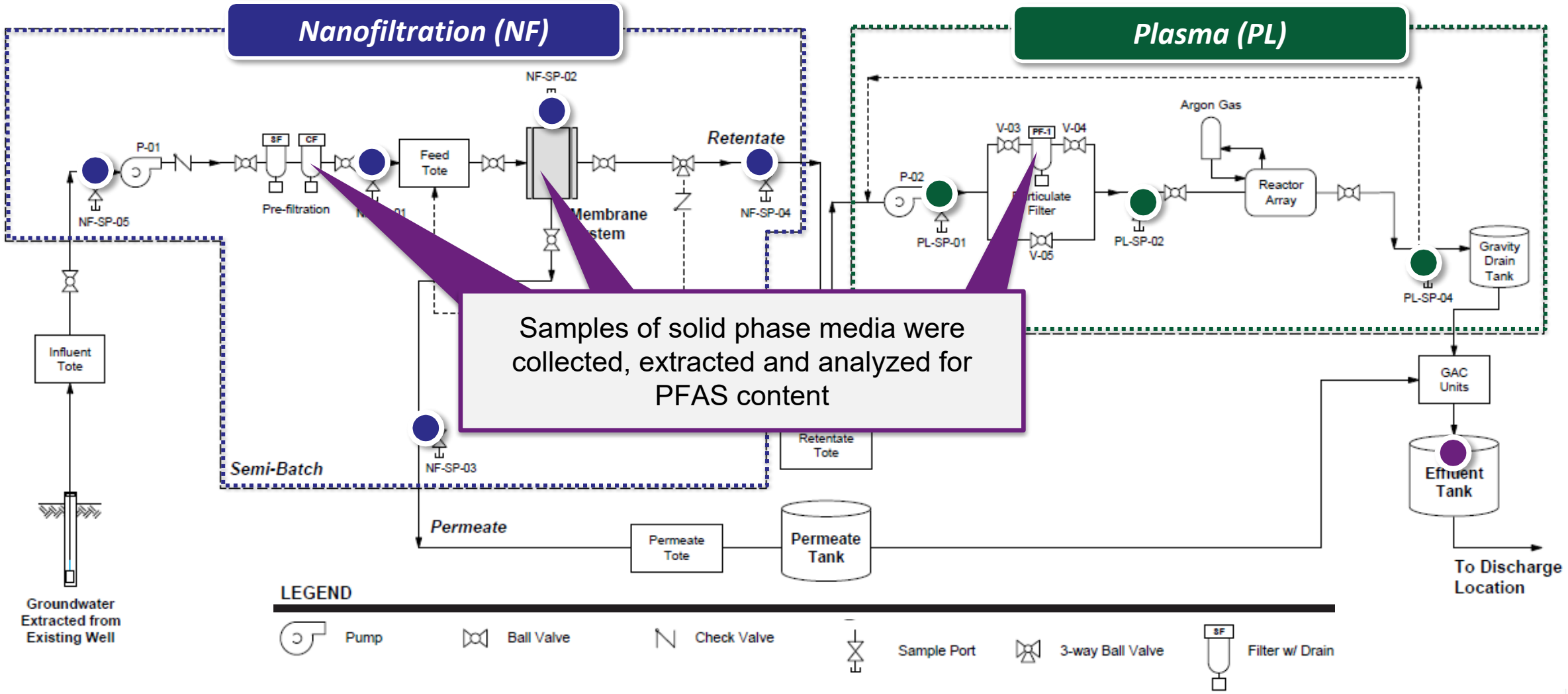
Field Demonstration: *In Action!*



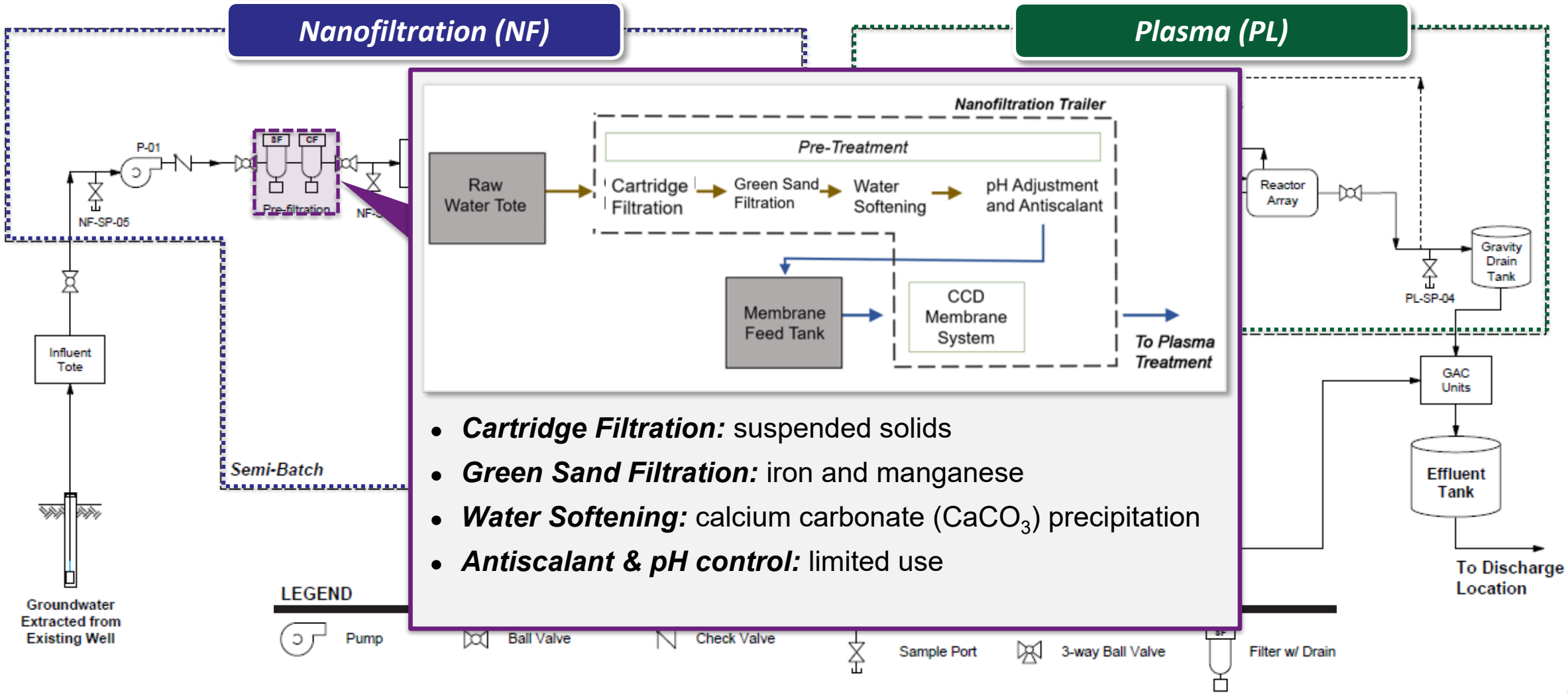
Field Demonstration: *Process Flow*



Field Demonstration: *Sample Locations*

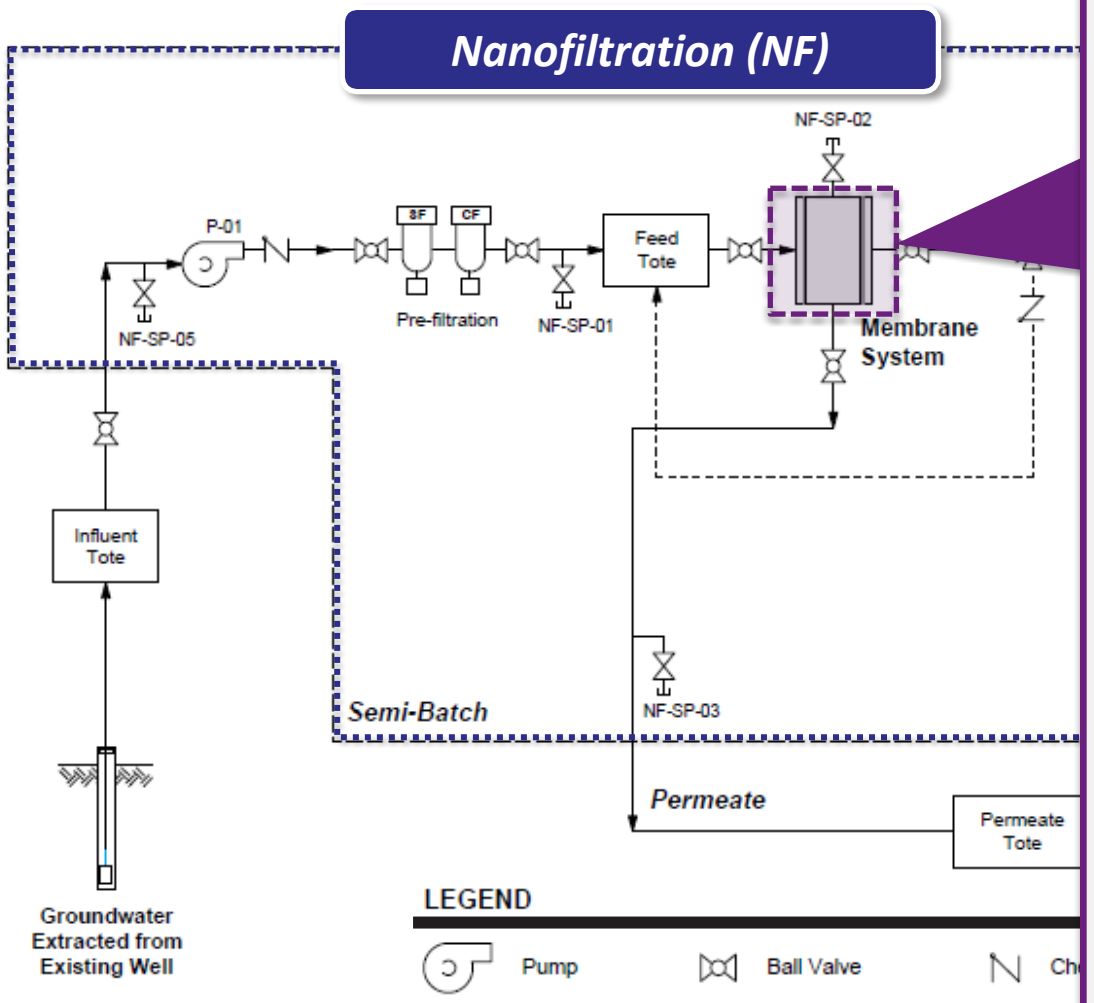


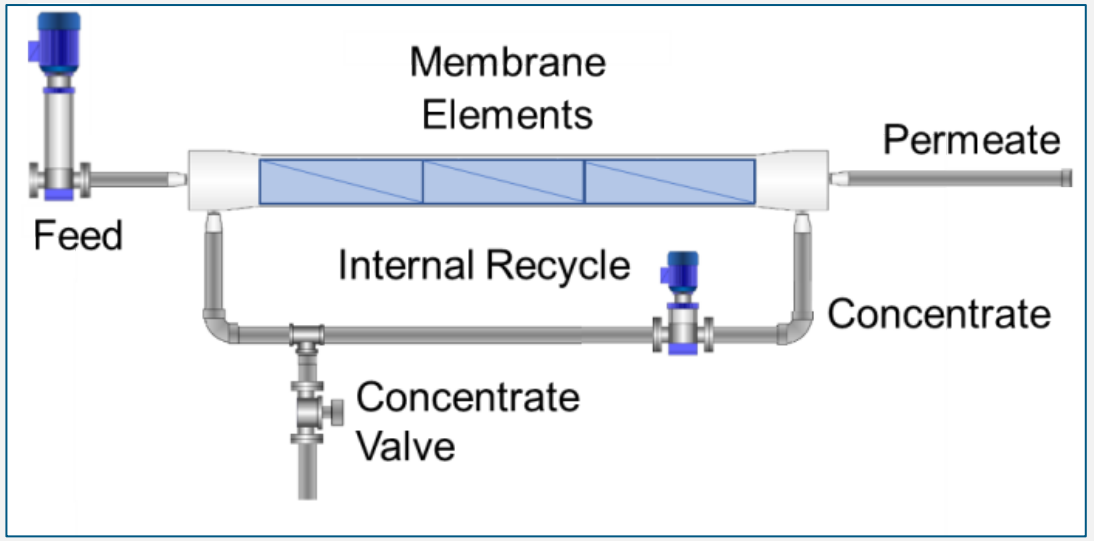
Process Flow: *Pre-treatment*



- ***Cartridge Filtration:*** suspended solids
- ***Green Sand Filtration:*** iron and manganese
- ***Water Softening:*** calcium carbonate ($CaCO_3$) precipitation
- ***Antiscalant & pH control:*** limited use

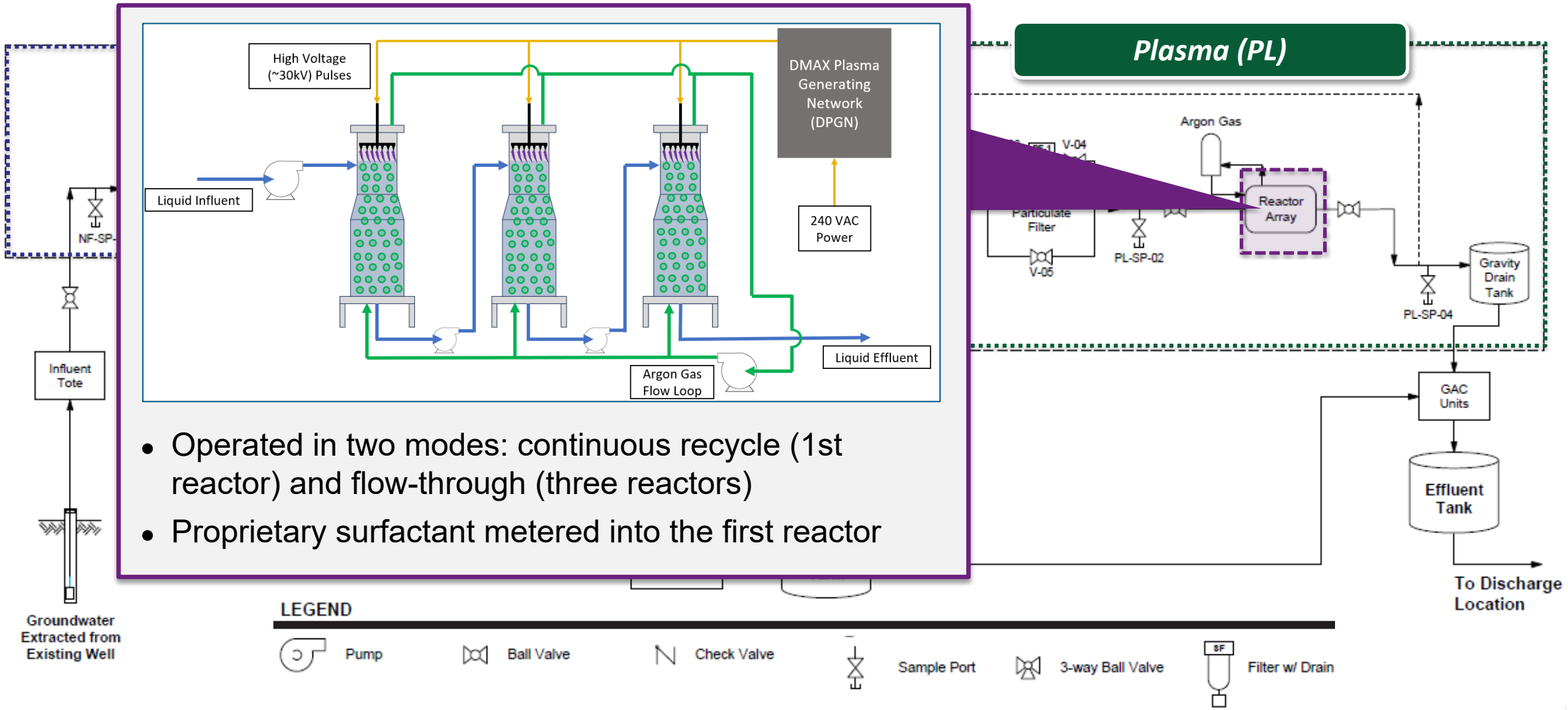
Process Flow: *Nanofiltration*





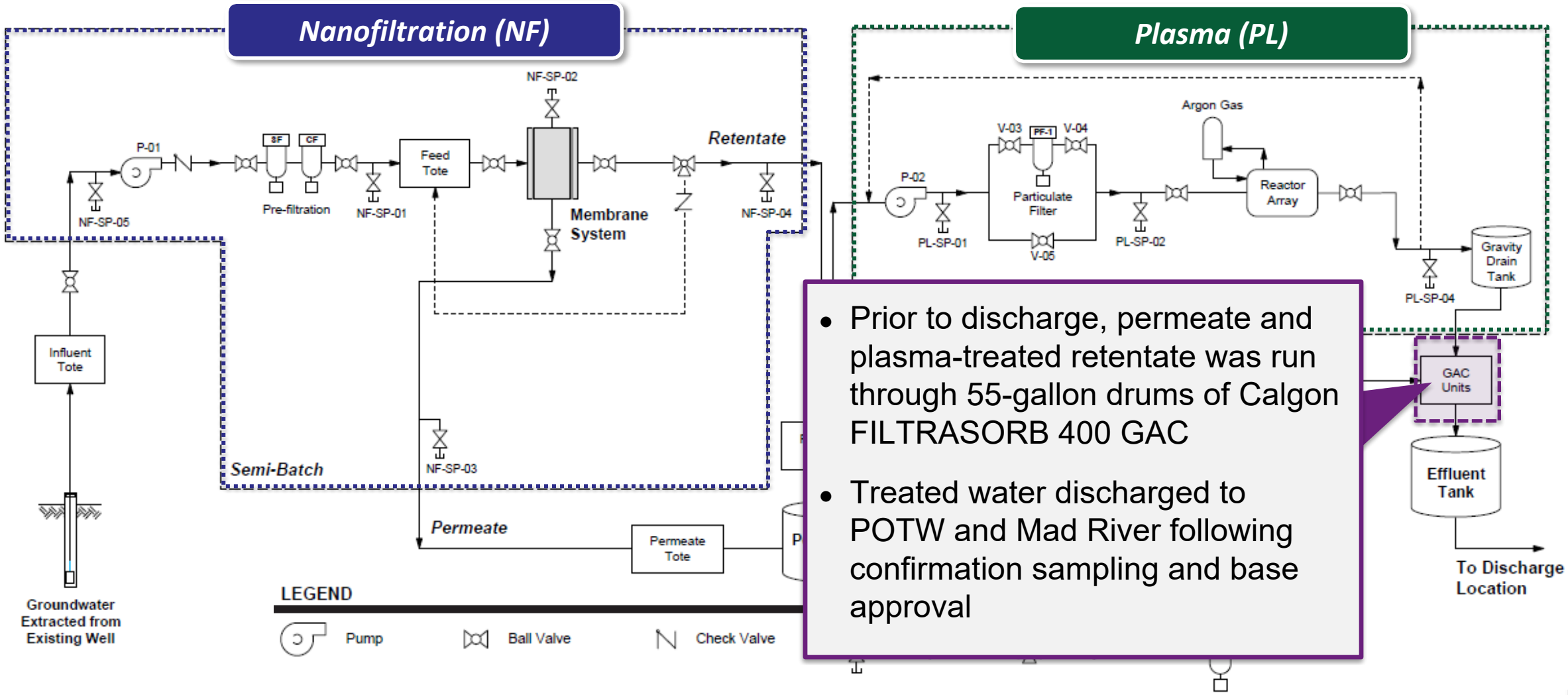
- During filtration, concentrate recirculated internally, concentrate valve closed
- Once a recovery setpoint is reached, concentrate valve opens
- With concentrate valve open, plug-flow flush displaces concentrate in system
- Concentrate valve closes, new cycle starts

Process Flow: *Enhanced Contact Plasma*



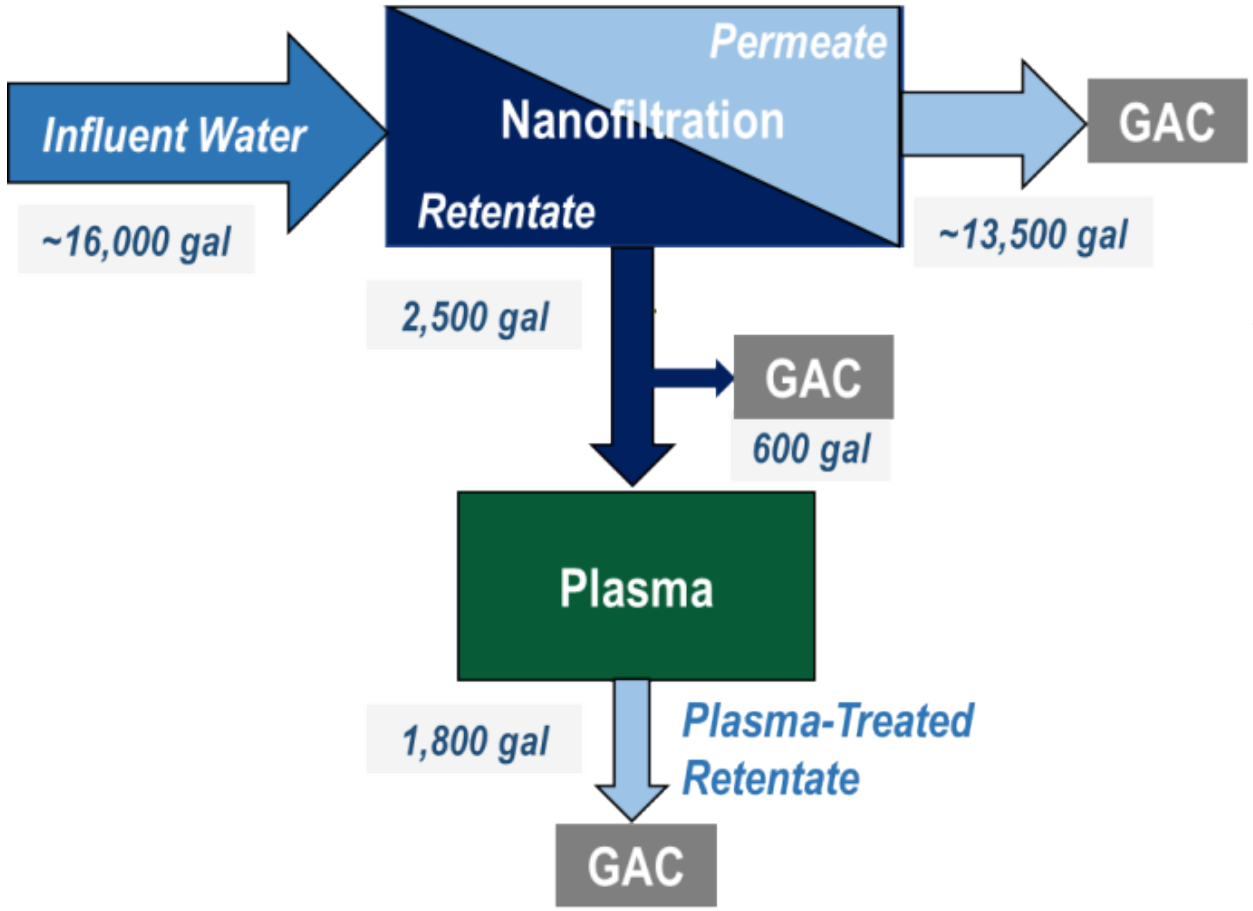
- Operated in two modes: continuous recycle (1st reactor) and flow-through (three reactors)
- Proprietary surfactant metered into the first reactor

Process Flow: *Polishing*



- Prior to discharge, permeate and plasma-treated retentate was run through 55-gallon drums of Calgon FILTRASORB 400 GAC
- Treated water discharged to POTW and Mad River following confirmation sampling and base approval

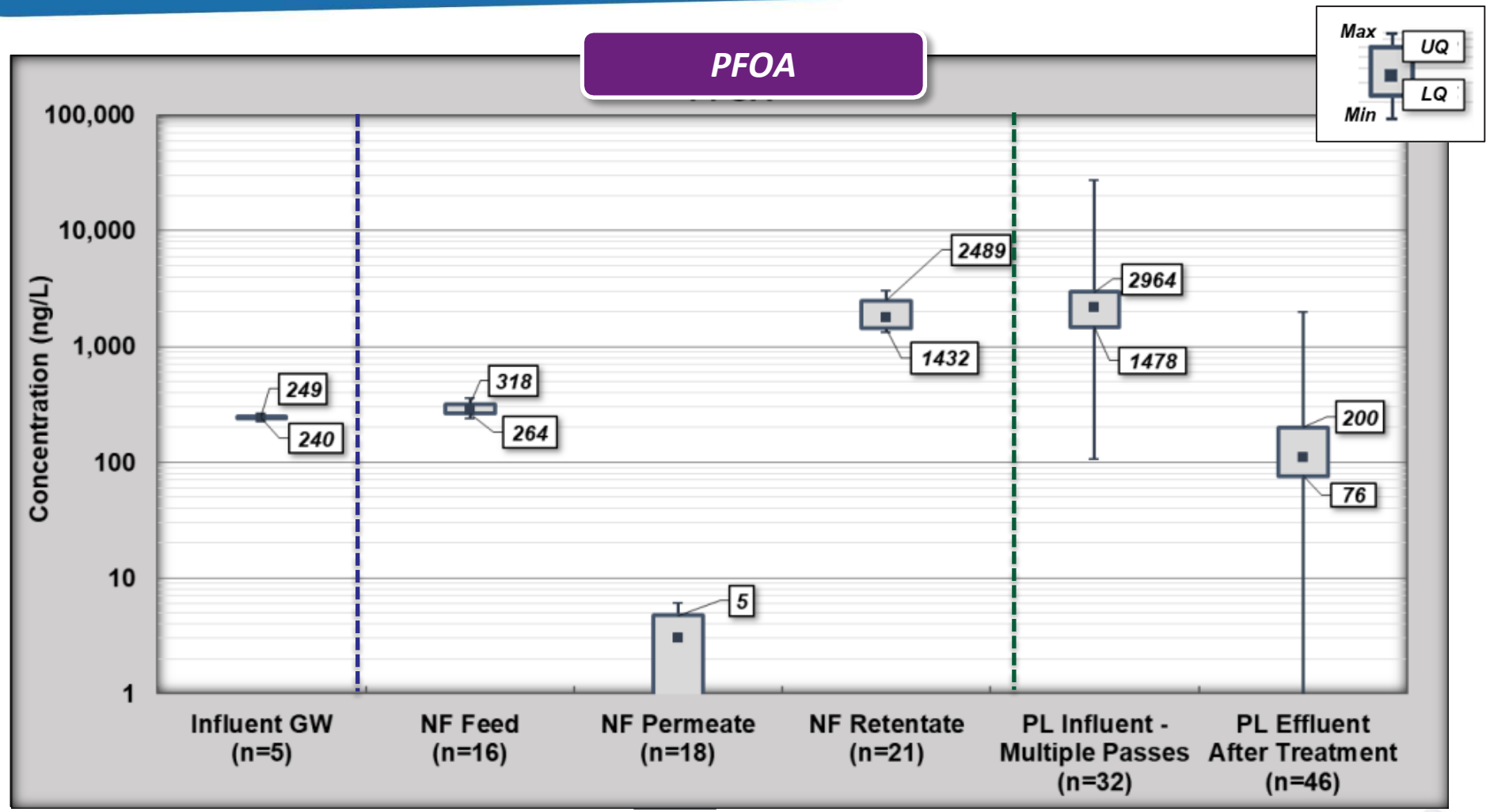
Results: *Treated Volumes*



- 16,000 gallons of PFAS-impacted groundwater
- Generated 13,500 gallons of treated permeate
- Generated 2,500 gallons of PFAS-containing retentate
- 1,800 gallons of retentate was treated using the enhanced contact plasma reactor
- All generated water was polished using GAC prior to discharge

System Performance: *PFOA*

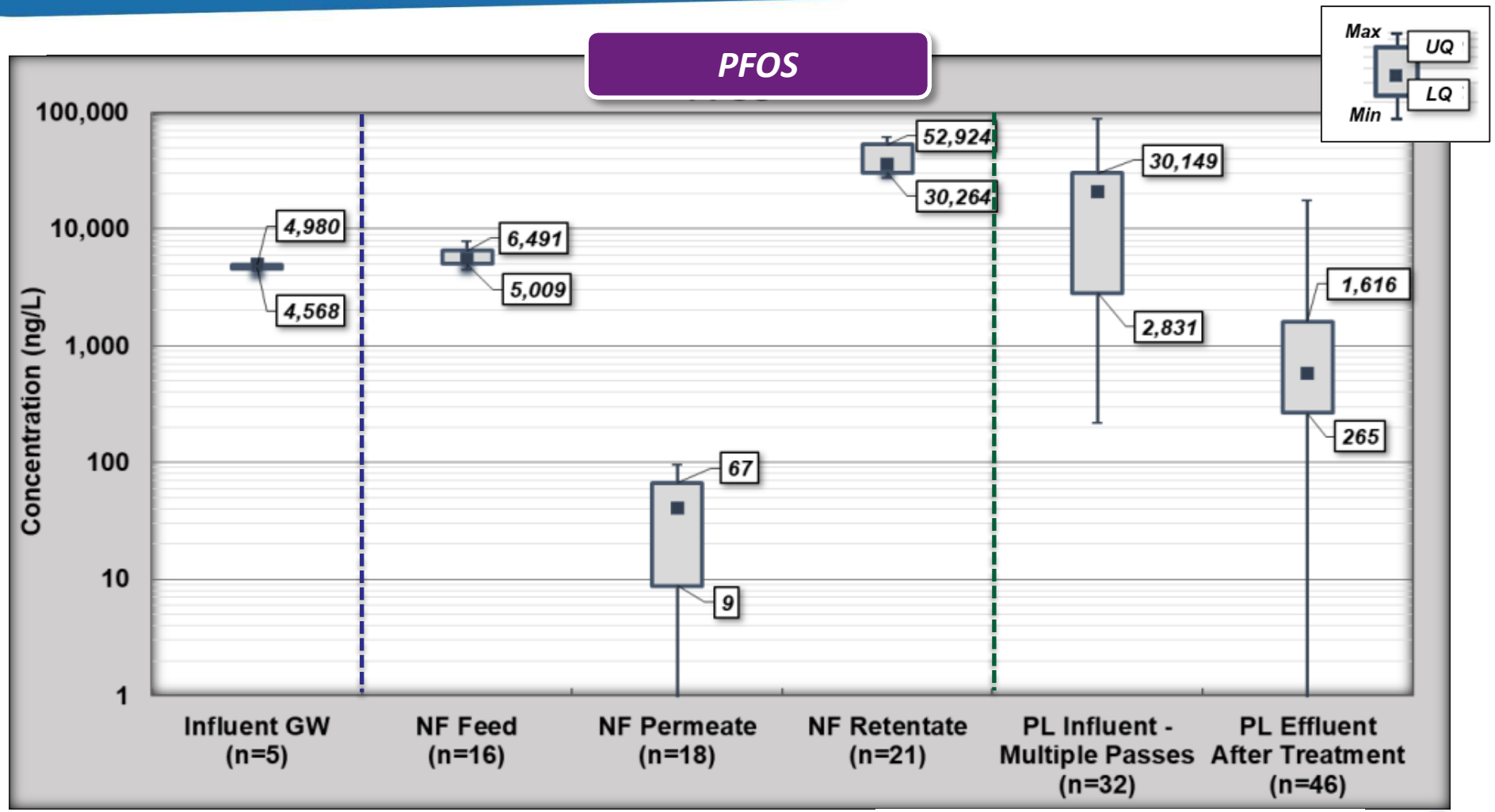
- **Pre-Treatment:** Minimal impact on concentrations
- **Permeate:** Below detection limits
- **Retentate:** ~10X concentration factor
- **Plasma Treatment:**
  - >90% reduction in concentrations
  - Variable results



PL = Plasma; NF = Nanofiltration

System Performance: *PFOS*

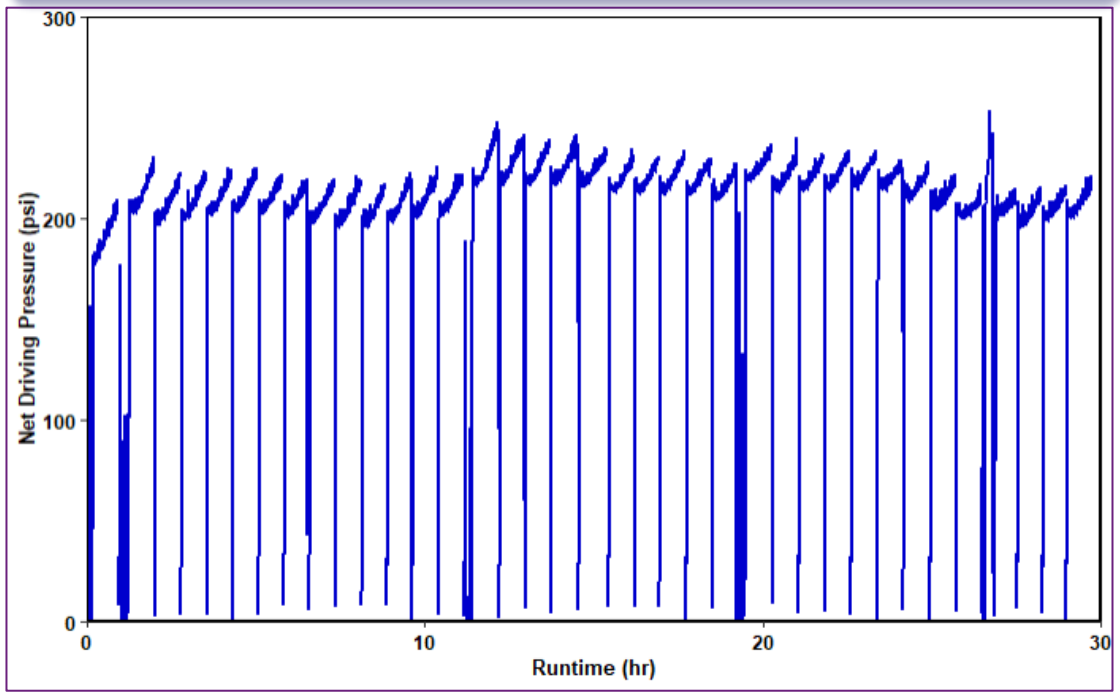
- **Pre-Treatment:** Minimal to low impact on concentrations
- **Permeate:** low concentrations
- **Retentate:** ~10X concentration factor
- **Plasma Treatment:**
  - Variable results



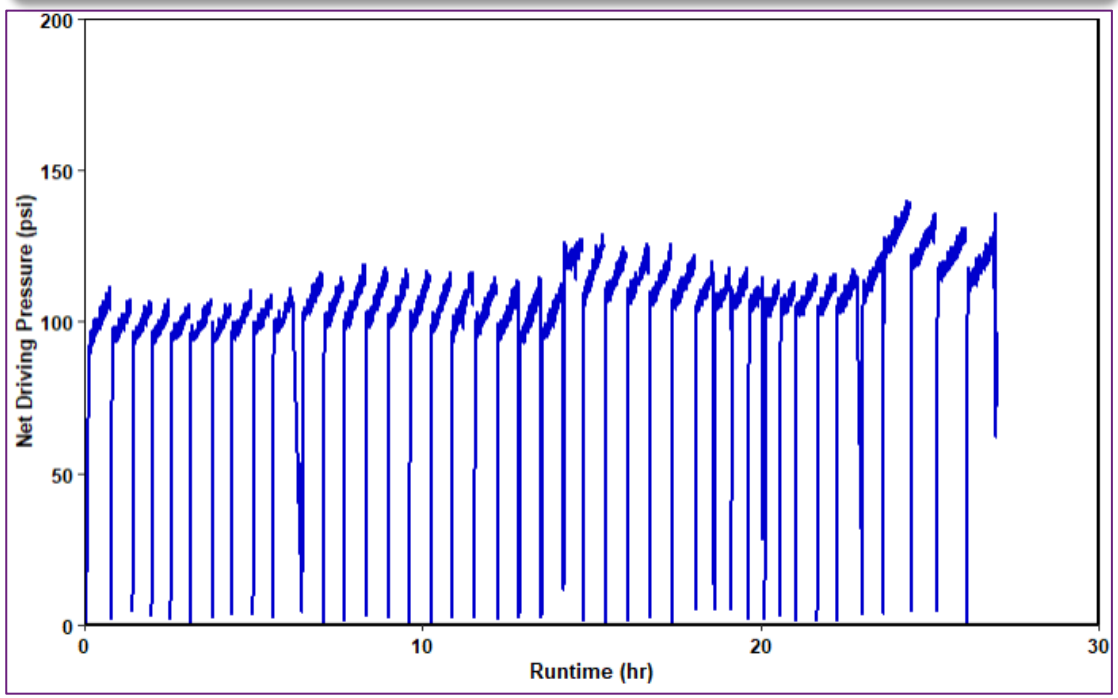
PL = Plasma; NF = Nanofiltration

Nanofiltration Performance:
Net Driving Pressure

CR100 Membrane: High Recovery (90%)



NF90 Membrane: High Recovery (90%)



- Consistent cycling indicates no fouling of membranes through experiments

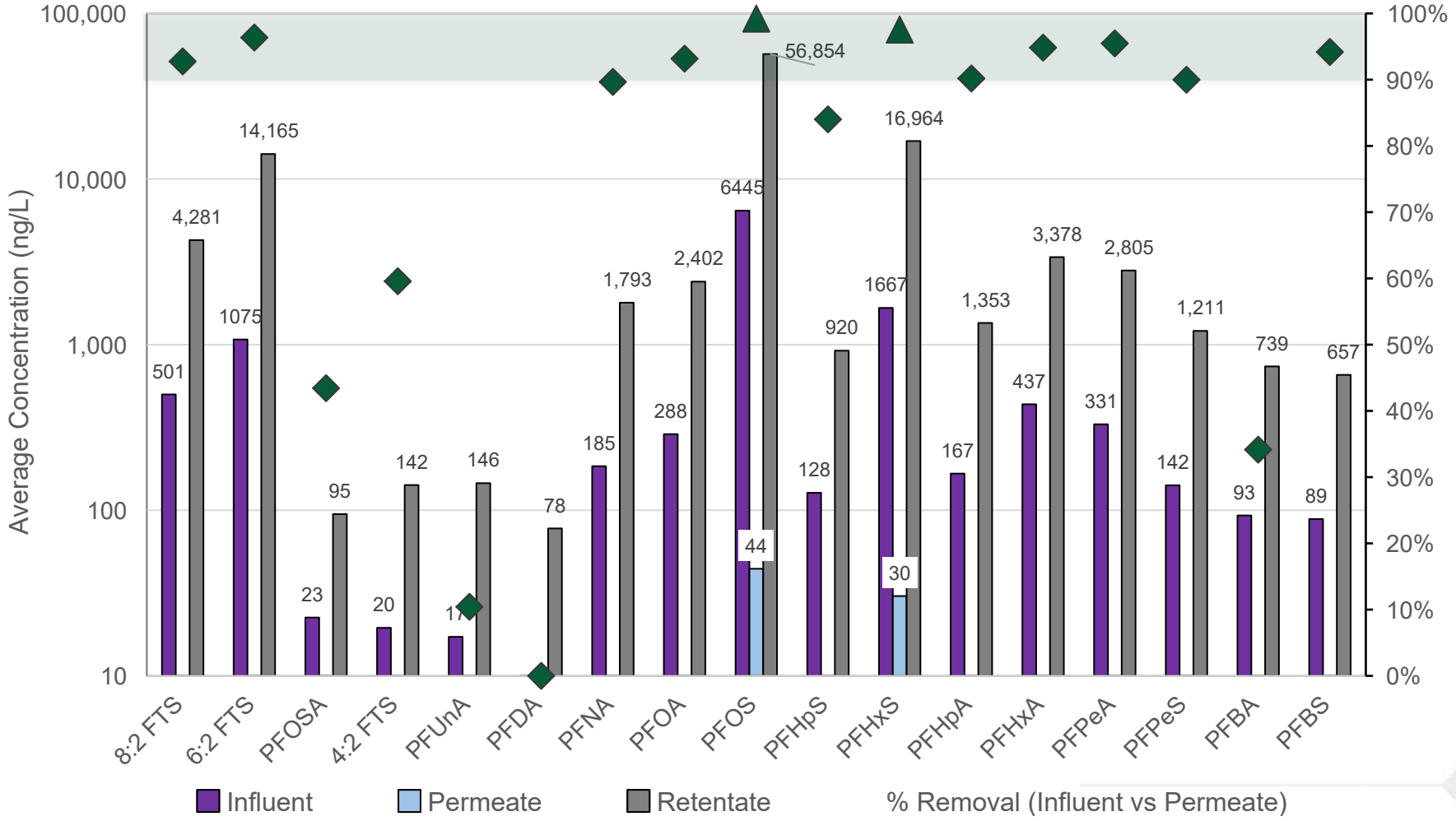
Nanofiltration Performance:
NF90 Membrane, High Recovery (90%)

Retentate:

- Achieved 7-13X concentration factors
- Consistent with recovery set point

Permeate:

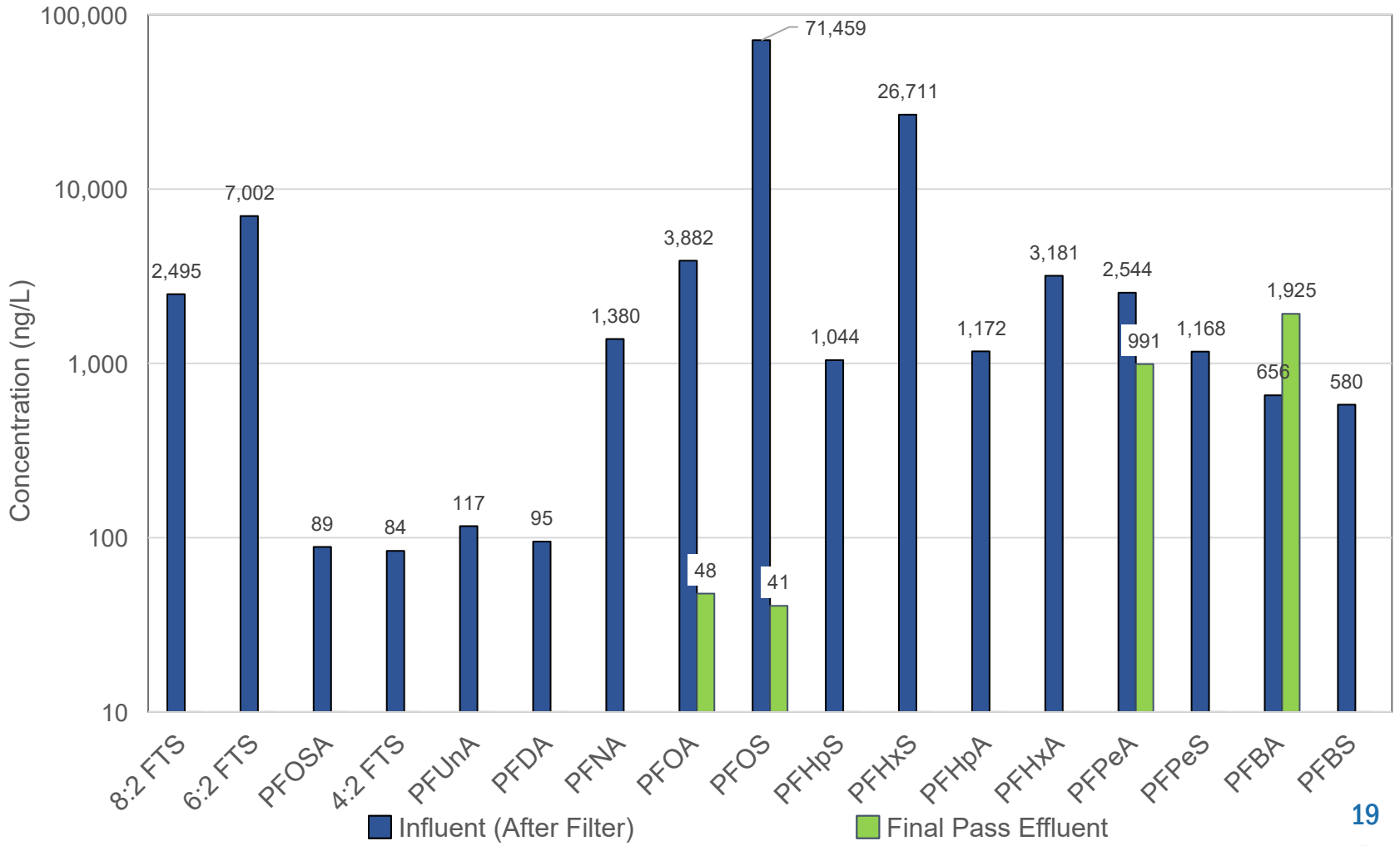
- PFOS and PFHxS detected at low conc.
- >90% removal for most compounds
- % removal calcs affected by detection limits



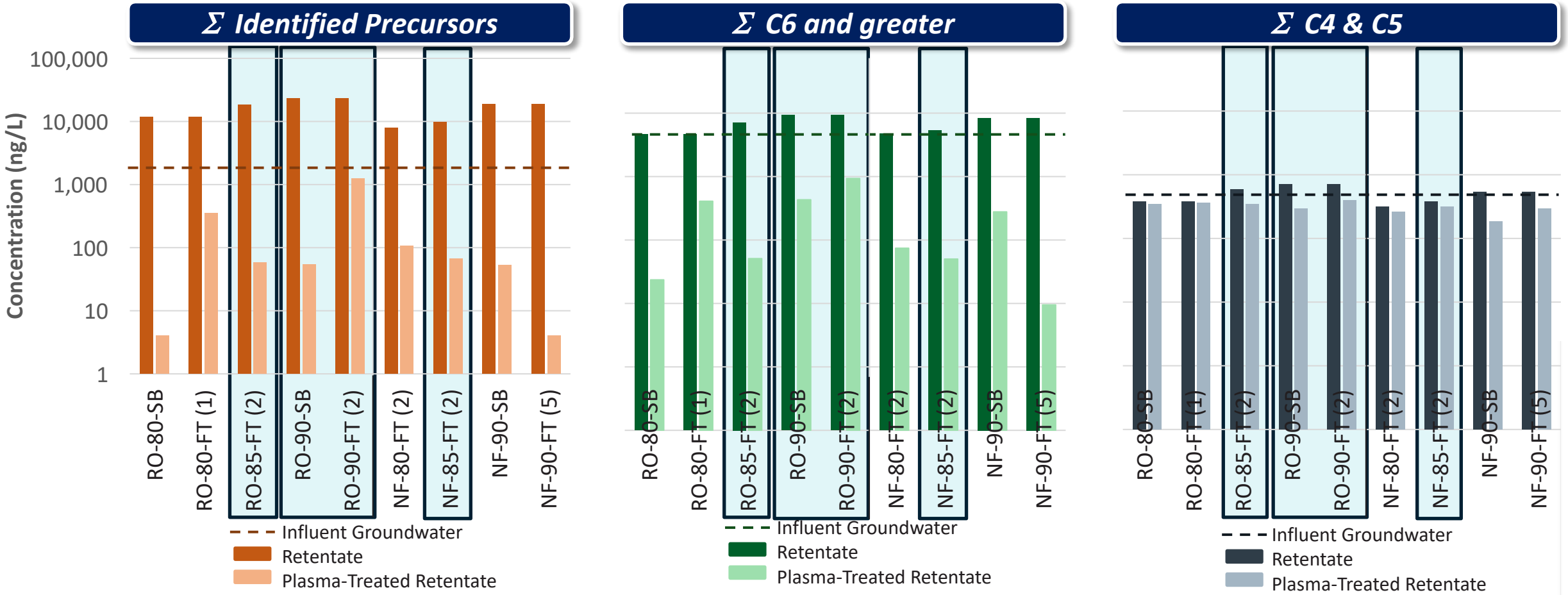
Plasma Performance:
Flow-Through

NF90 Retentate (90% Recovery)

- Strong removal of precursors and long-chains
- >90% reduction of PFOA and PFOS
- Production of PFBA and slow decline of PFPeA attributed to degradation of long-chain PFAS & unidentified precursors



System Performance:
Overview



- **Nanofiltration:** Highest concentration factors observed for CR100 membrane at 90% recovery
- **Plasma:** Similar removal with retentate from each membrane

Key Points: *Overview*

Nanofiltration

- ~13,500 gallons of treated permeate
  - >5 – 10X concentration of source water
- >99% PFAS separation for most PFAS
  - PFOS detected in permeate
- CR100 performed better than NF90
  - Minimal permeability loss

Enhanced Contact Plasma

- 1,800 gallons of treated retentate
- Percent Removal:
  - Precursors: 19-99% (median = 91%)
  - >=C6 PFAAs: 53-97% (median = 93%)
  - C5/C4 PFAAs: -125% - 97% (median = -6%)
- Potential cross-contamination within the system

Acknowledgements

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ESTCP

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Electrochemical Oxidation Testing

QUESTIONS?

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