Performance of In Situ Biochar Stabilization Integrated with TreeWells® to Remediate PFAS in Groundwater

Len Mankowski, MS, WSP, Traverse City, Michigan
Dora Chiang, PE, PhD, Jacobs, Atlanta, Georgia
Janice Adams, EGLE, Gaylord, Michigan

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Problem

Former Alpena Hide & Leather, Alpena, Michigan

History

- Tannery (1890s-1940s)
- Burned to ground in 2005 (AFFF-use suspected)

Setting

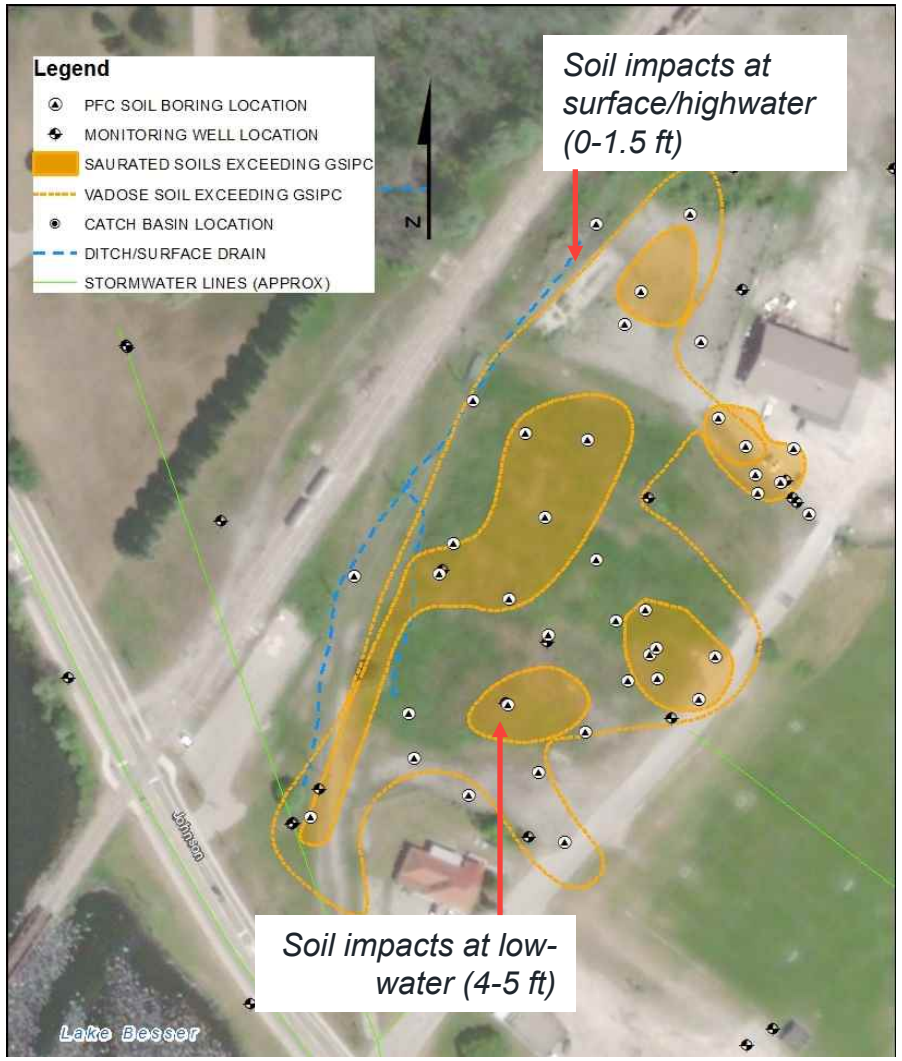
- Located near Thunder Bay River (Ninth Ave. Dam)
- Lake Huron ~1 Mile
- Groundwater seasonally vents to surface at site
- Historical storm water infrastructure in source connects to municipal system & Thunder Bay River

Problem

PFAS Source

- Tannery burned to ground in 2005 (AFFF-use suspected)
- PFAS in surface soil is widespread (0-2 feet)
- PFAS hotspots extend to low water capillary fringe (4-5 feet)

PFAS	Soil	
	ng/g (ppb)	*f* (%)
PFBA	ND	0%
PFBS	5.7	11%
PFHxS	43	56%
PFOS	264	63%
PFOA	5.4	9%
Total (537)	14 PFAS; PFAS in 76% samples	

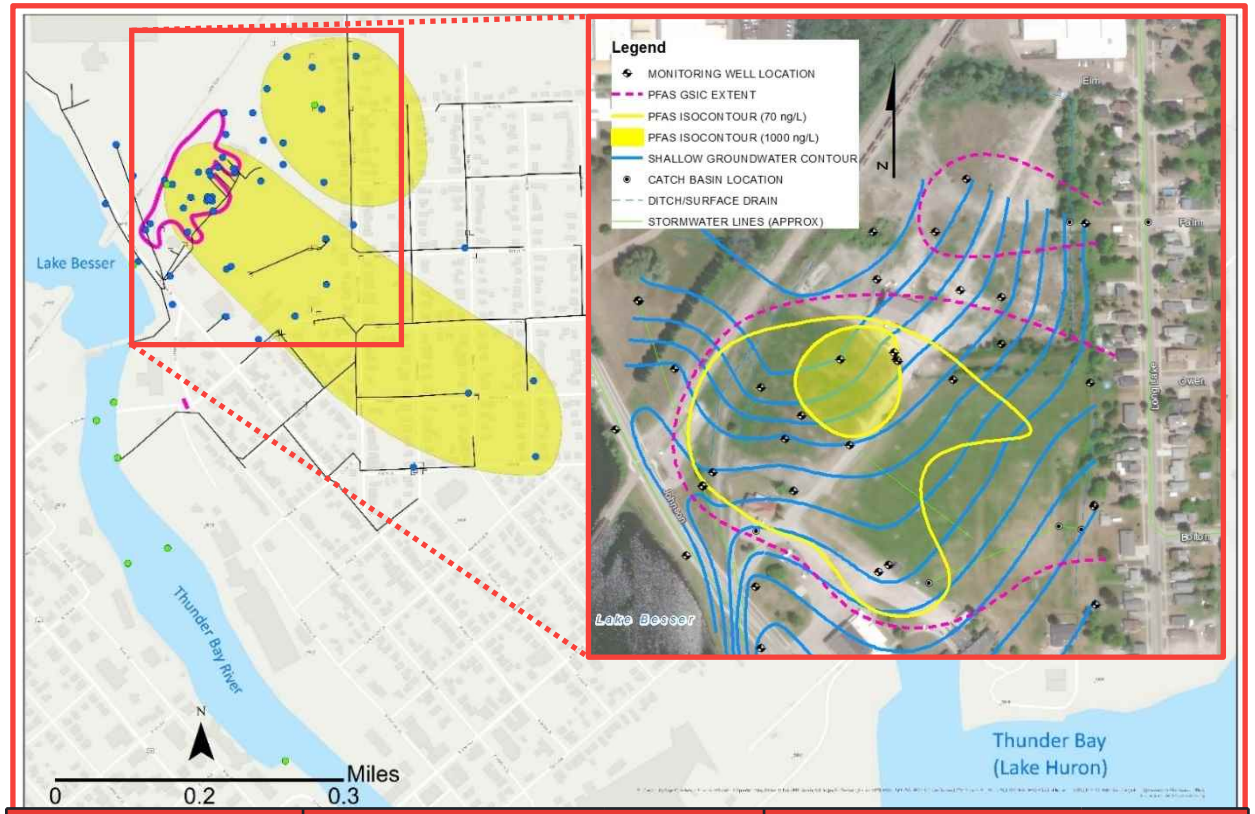


Problem

PFAS in Groundwater

- Dilute PFAS plume migrating to Lake Huron
- Municipal water serves downgradient residents
- Groundwater infiltrates into storm water infrastructure (on-/off-site) & discharges to river
- Groundwater seasonally vents to surface

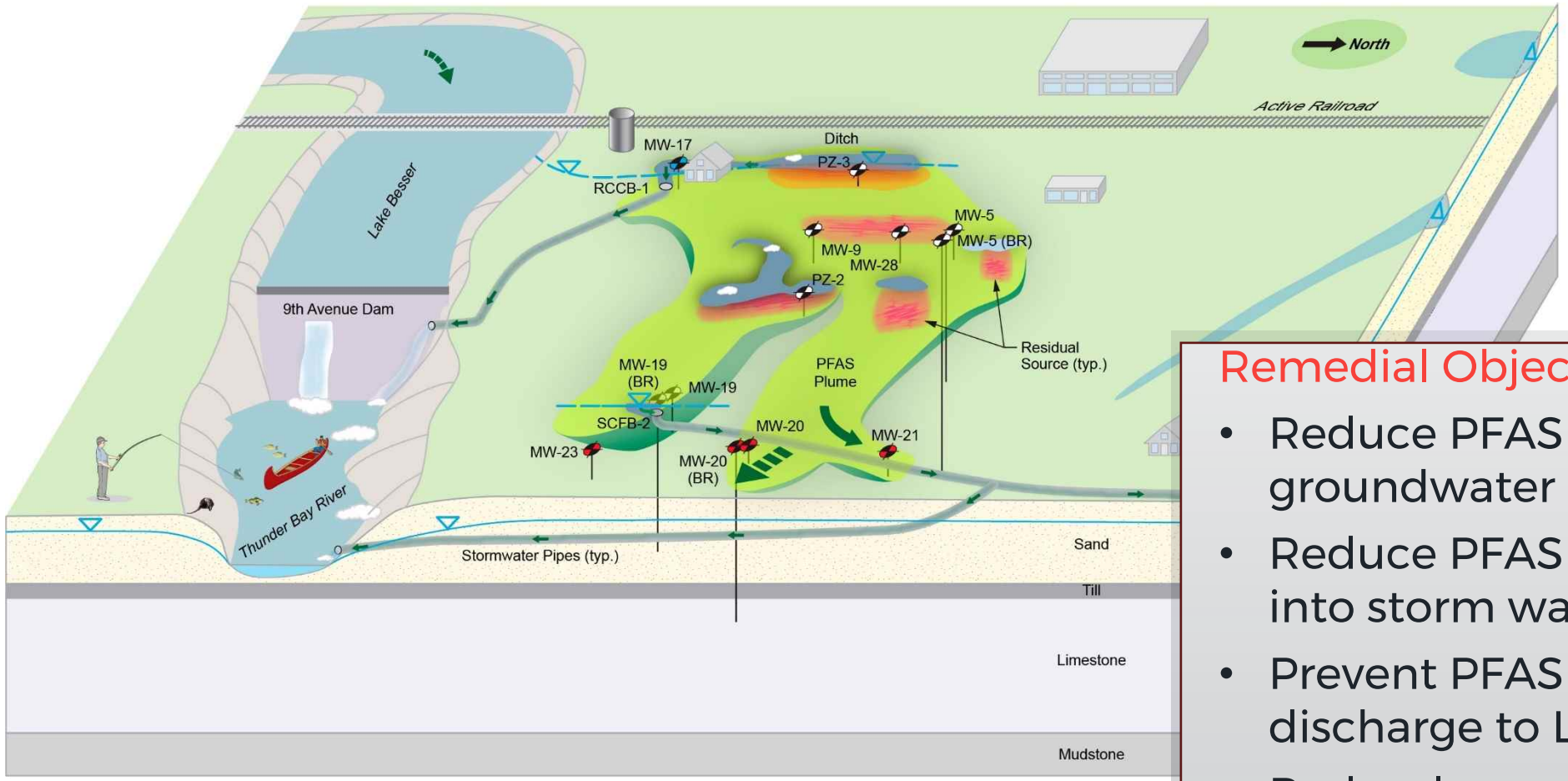
Hydrogeology not conducive to P&T; PFOS, PFHxS & PFOA > Surface Water Quality Values



PFAS	Soil		Groundwater	
	ng/g (ppb)	*f* (%)	ng/L (ppt)	*f* (%)
PFBA	ND	0%	493	92%
PFBS	5.7	11%	*3,140*	85%
PFHxS	43	56%	***15,400***	79%
PFOS	264	63%	**8,270**	74%
PFOA	5.4	9%	**804**	79%
Total (537)	14 (*f*-76%)		20 (*f*-92%)	

Problem

CSM & Remedial Objective



Not To Scale

Remedial Objectives:

- Reduce PFAS flux in groundwater at source
- Reduce PFAS migration into storm water
- Prevent PFAS plume discharge to Lake Huron
- Redevelopment: reduce seasonal flooding

2018 Biochar Pilot – Retention near Source?

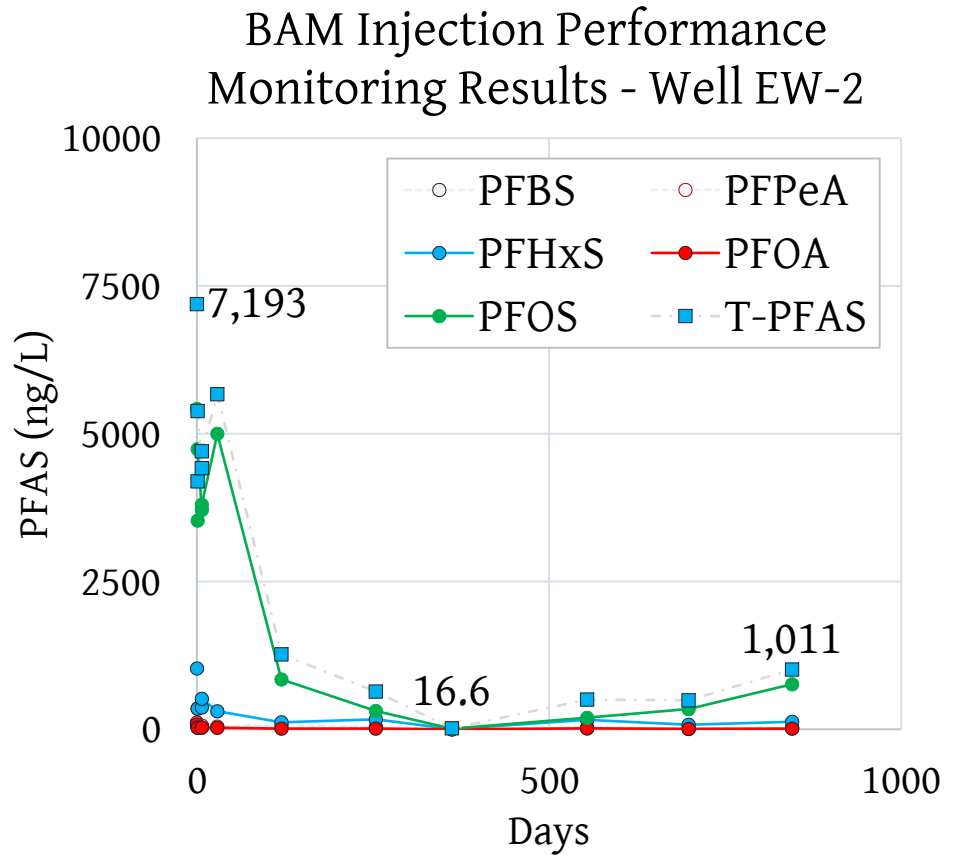
Bioavailable Absorbent Media™ (BAM)

- Injectable (<30 µm diam.) & Soil Mixing (up to 1 cm) Blends
- Goes where it is placed
- Cost effective
- Sustainable (no surfactants; repurposed "waste")

Two Pilots

- **Injection** to treat PFAS >7 ppb
  - Reduced levels below criteria in 1-yr
- **Soil Mixing** to treat PFAS >9 ppb
  - "Instant" reductions in PFOS (<criteria) followed by slow, ~ linear rebound

No help with seasonal flooding



Direct Push Injection using "Push-Pull"

Excavator based soil mixing

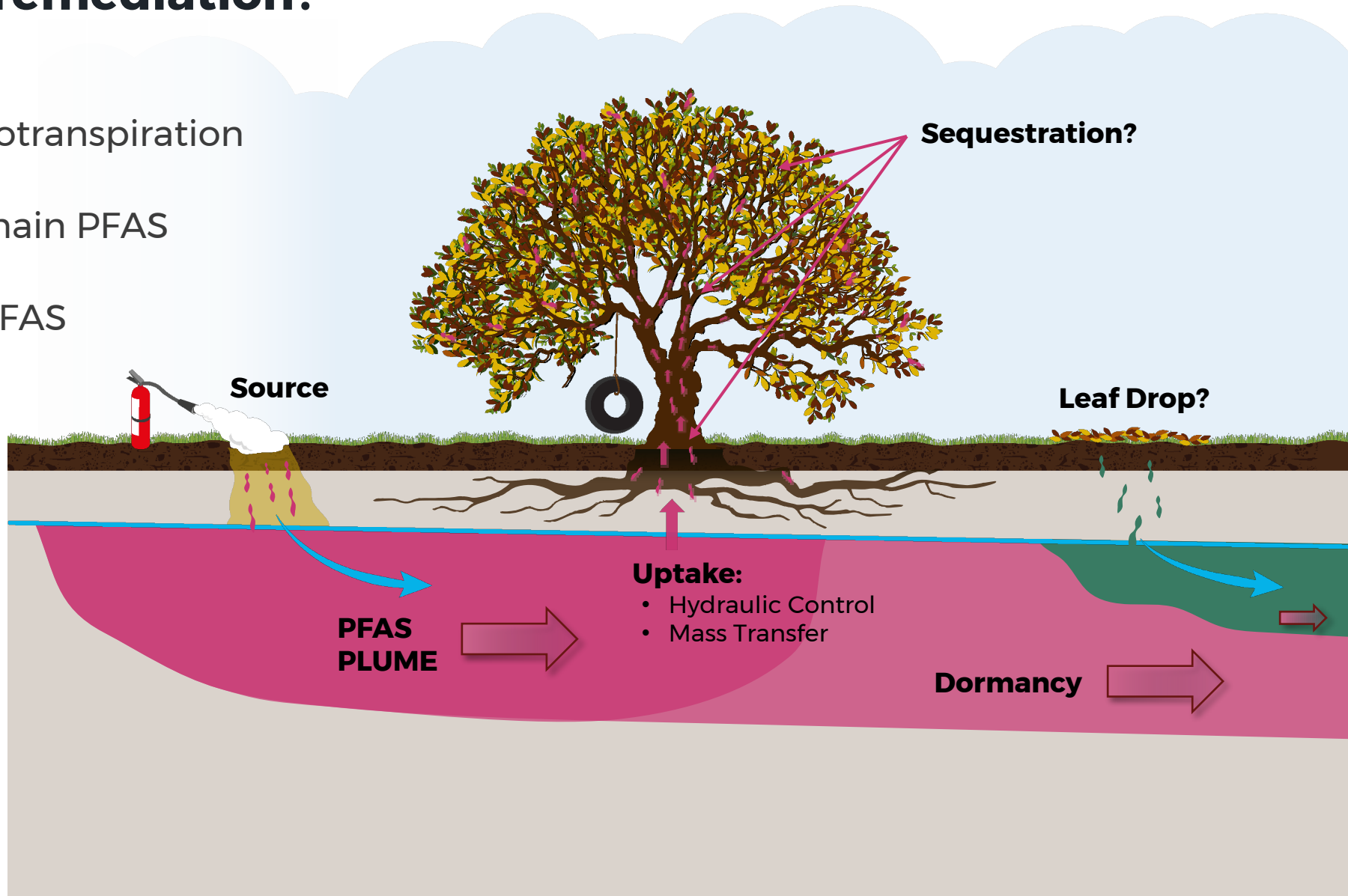
Role for Phytoremediation?

Advantages

- Contain via evapotranspiration (pumping)
- Enhance short chain PFAS removal
- Trap/sequester PFAS
- Resilient; low O&M costs

Concerns

- PFAS mass transfer
- Management?
- Design for dormancy



Combining in-situ Carbon with Phytoremediation

Contain (Phtyo)

- Evapo-transpiration pumping
- Inward directed hydraulic gradients

Trap (Carbon)

- PFAS sorption onto BAM
- Secondary sorption into tree tissue

Treat

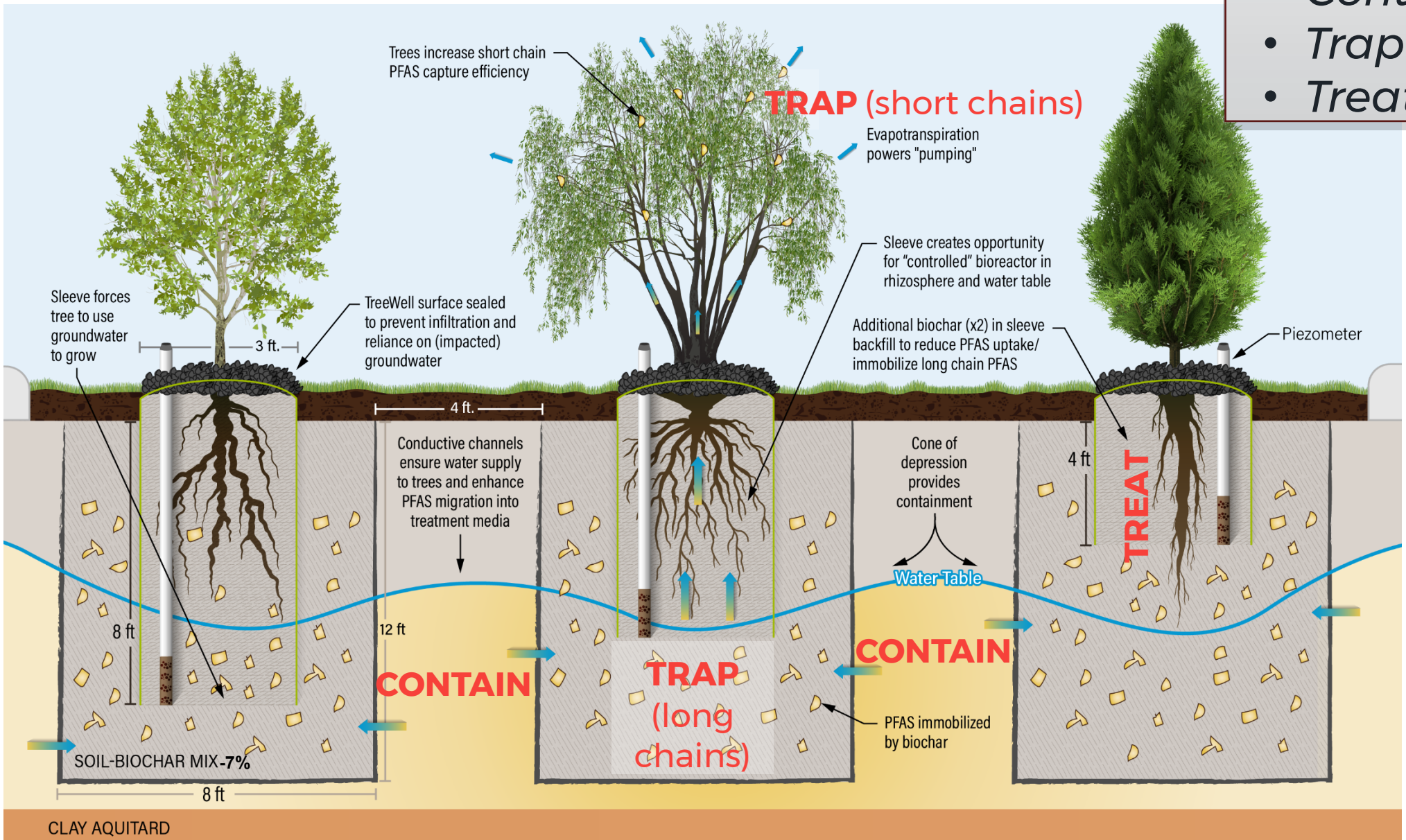
- PFAS removed from ground-water
- Reduce PFAS uptake into tree tissue
- Overcome short chain desorption losses

Destroy?

- Concentrate PFAS in media
- Future woody tissue incineration?
- Potential bioreactor?

BAM - TreeWell® Conceptual Design

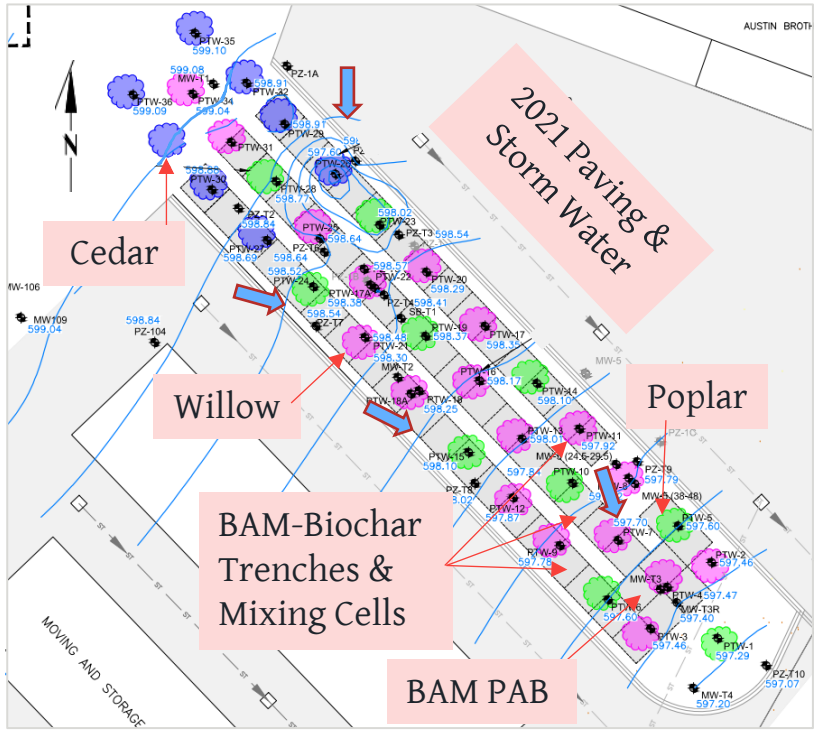
Remedial Approach
- Contain
- Trap
- Treat



2022 TreeWell Pilot Test

Installed new storm water infrastructure to segregate & manage precipitation

- Soil mixed BAM (7% by volume) into 3, 8 x 150 ft long trenches, 10-12 ft deep
- 35 TreeWells with 14% BAM in sleeves
  - 3-ft diam. Boreholes on 16-ft centers
  - Piezometers in each sleeve
  - 18 willows (longterm – pumpers)
  - 10 hybrid poplar (early growth)
  - 8 cedars (seasonal pumping)
  - Conductive channels and BAM PAB

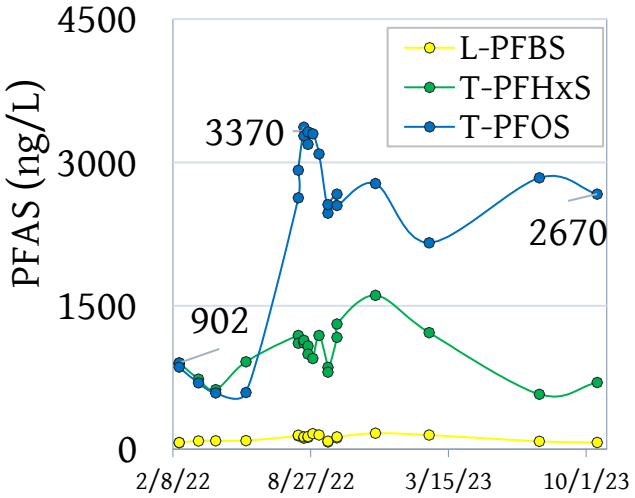


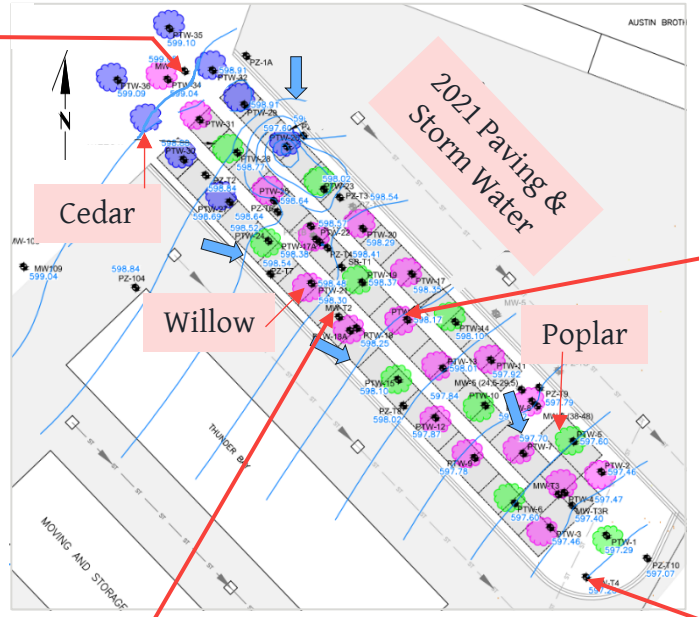
Groundwater Results

Upgradient

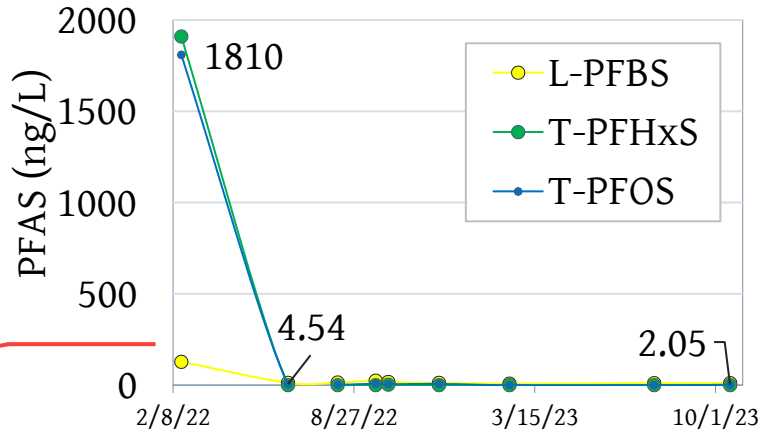
PFAS levels increase in first season (pull)

MW-T1 ~Background





PTW-16 (Willow)



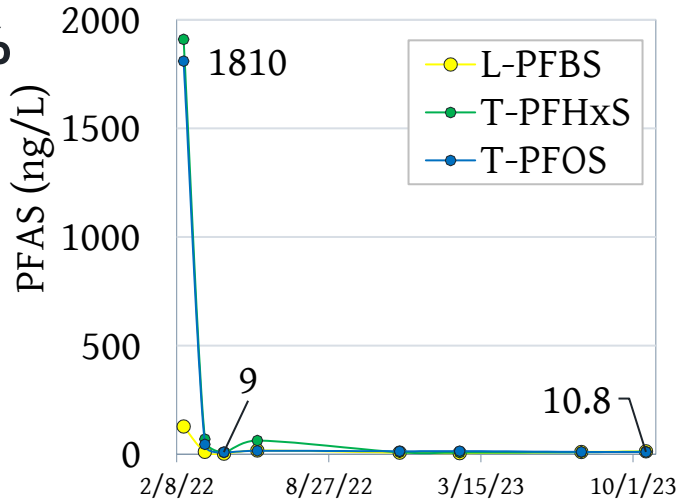
TreeWells

- **PFOS: 99.9% reduction**
- PFBS: 91% reduction

BAM Trench

- **PFOS: 99.4% reduction**
- PFBS: 89% reduction

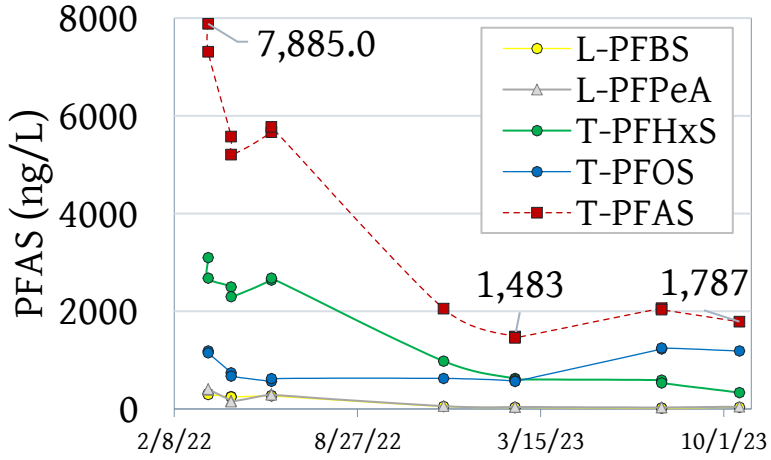
MW-T2 (BAM)



Downgradient

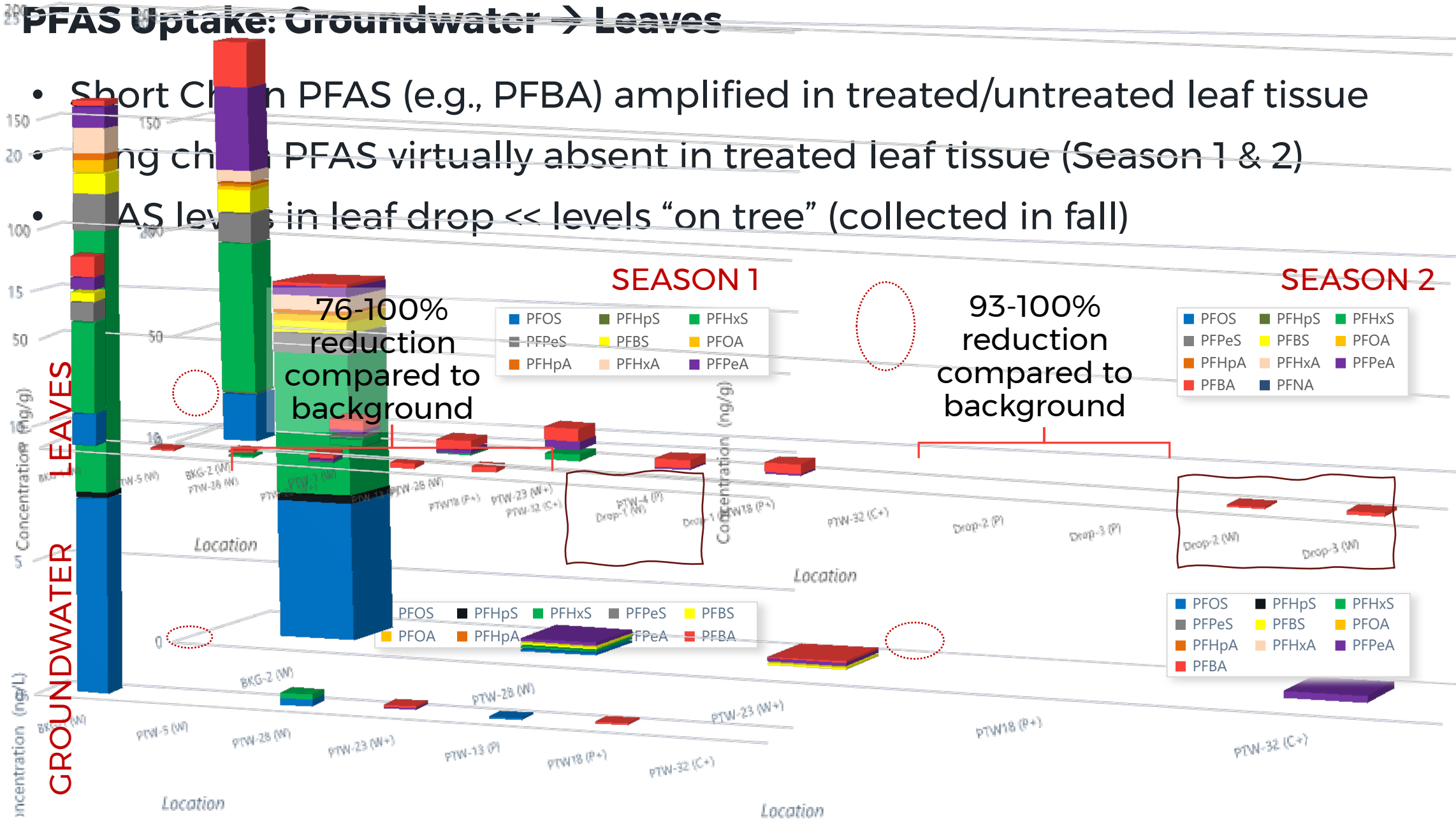
- Short chain PFAS & PFHxS reduced ~80+%
- Little change in PFOS (residual)

MW-T4 (Downgradient)



PFAS Uptake: Groundwater → Leaves

- Short Ch[illegible]n PFAS (e.g., PFBA) amplified in treated/untreated leaf tissue
- [illegible]ng ch[illegible] PFAS virtually absent in treated leaf tissue (Season 1 & 2)
- [illegible]AS lev[illegible] in leaf drop << levels "on tree" (collected in fall)



PFAS Uptake: Soil → Woody Tissues

Buck damaged two trees allowing sampling of roots and trunks in September, Season 1:

- Only PFHxS & PFOS were detected in background woody tissues and soil
- Except for a single detection of PFHxA, no PFAS detected in treated woody tissue
- PFPeA was present in all soils analyzed from Treewell® sleeves

Do PFAS move with xylem seasonally (up in spring, down in fall)?

Summary and Future Research

Contain

- Inward directed hydraulic gradients established.
- PFAS drawn into treatment array (upgradient).
- Total PFAS decreased by >80% downgradient of treatment zone, including short chain PFAS. Downgradient PFAS reductions masked by residual PFOS.
- No groundwater venting to the surface and moving into storm water via overland flow since paving / treewell planting.

Trap and Treat

- BAM reduced PFOS & PFHxS in groundwater by >99%.
- No "rebound" yet observed in treated area.
- Short chain PFAS present in groundwater are trapped in tree leaves; relative concentrations amplified.
- PFAS uptake into leaves reduced by >93% (Season 2) and are lower or non-detect in leaf drop.
- No PFAS were detected in roots and trunk tissues analyzed from BAM-treated TreeWells.

Future Work

- Expand system along downgradient property boundary
- Internal nutrient cycling of PFAS?
  Decreased PFAS levels in leaf drop suggest some PFAS may be pulled back into the tree or soil in fall (PFPeA).
- Destruction?
  BAM-TreeWell systems provide a "controlled" and "slow" experimental environment in root sleeves ("bioreactor"?).

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Thank you

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