PFAS Stabilization: Comprehensive Bench Scale Evaluation of Amendments, Dosage, and Binders

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Client: Public Services and Procurement Canada and Department of National Defence

Partners/Suppliers: SiREM, BV Laboratories, Rembind, Cetco, Calgon

October 2025

SLR

Major Sources of PFAS Contamination

- Aqueous Film Forming Foams (fire response or training areas)
- Waste Facilities (WWTP, landfills, biosolids)
- Oil and Gas Facilities (surfactants, lubricants, drilling fluids)

PFAS Toxicity

Increases in cholesterol levels (PFOA, PFOS, PFNA, PFDA)

Changes in liver enzymes (PFOA, PFOS, PFHxS)

Small decreases in birth weight (PFOA, PFOS)

Lower antibody response to some vaccines (PFOA, PFOS, PFHxS, PFDA)

Pregnancy-induced hypertension and preeclampsia (PFOA, PFOS)

Kidney and testicular cancer (PFOA)

State of Knowledge and Why do This Study

- DND remediation options analysis
- State of knowledge – PFAS contaminated soil management options
  - Landfill
  - Incinerate
  - Alternate options – physical separation; fixation/stabilization
- Stabilization research lacked generalized dosing information
- Challenging to select optimal amendments and dosing to cost-effectively achieve desired outcomes
- Goal was to meet project needs and close data gap for others

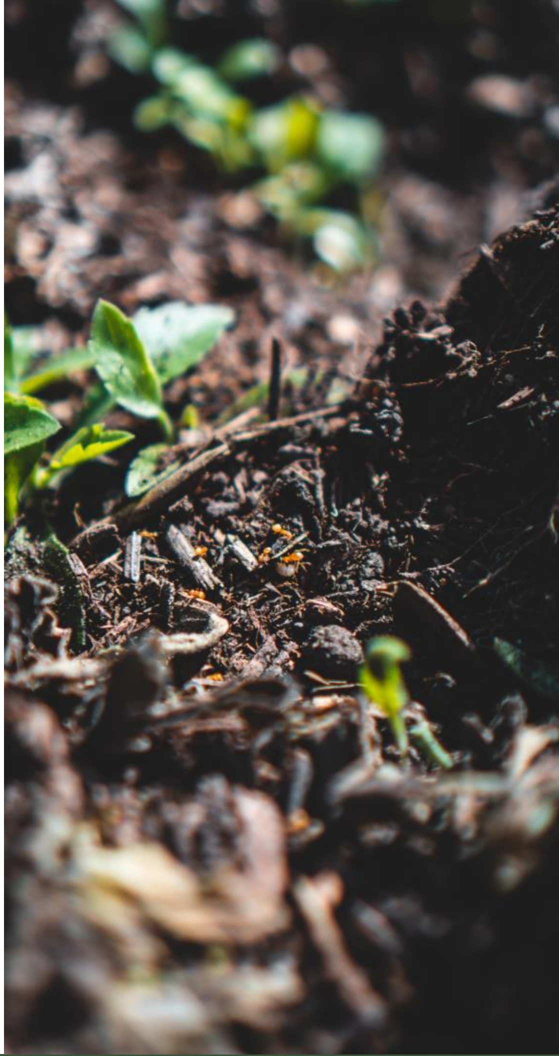
Study Objectives

1. What is the relative performance of proprietary and non-proprietary amendments?
2. Dosing - How much amendment is needed to successfully stabilize PFAS?
3. Does adding binders (e.g. cement) improve performance and/or cost-effectiveness?
4. Can we assess project quality with proxy measurements?
5. Can we apply site-specific data to other sites?

Study Design

Design

- 3 Amendments, 1 binder (i.e., Portland cement)
- 1 soil type
- 4 dosing data points (0.2, 0.5, 1.0 and 2.0%wt)
- Multiple analyses TOPA, LEAF 1314 and 1315, SPLP, compaction, hydraulic conductivity testing, geotechnical analyses,
- Treat PFOS concentration of at least 1.5 mg/kg to match site conditions
- Study timeframe: November 2022 – January 2024



Methods

Analysis Methods

METHOD	DESCRIPTION	WHY?
Leaching Procedures		
LEAF 1314	EPA method, leaching by percolation through a permeable material. Increasing L/S ratios (x6) from 0.2 to 2 mL/g-dry show how leachate concentrations relate to cumulative contaminant release.	Worst-case initial leachate concentrations (‘low’ L/S ratio), insight into long-term equilibrium pore water concentrations / cumulative release over time
LEAF 1315	EPA method, leaching via diffusion from a monolithic or compacted granular material, simulates mass transfer rates changes over time by periodically changing the immersion water.	Most representative for solidified soils
SPLP 1312	EPA method, leaching by percolation of acid rain through waste to groundwater (fixed pH). Uses a single ‘high’ L/S ratio (or ‘dilution attenuation factor’) of 20 mL/g-dry.	Tested as a potential proxy for LEAF 1314 - readily available and quick
Analytical Procedures		
PFAS	PFAS via LC/MS-MS	Document change in PFAS concentration over study steps
PFAS via TOPA	total oxidizable precursor assay [TOPA]. Oxidation forces precursors to transform into target PFAS.	Assesses precursors in amended and un-amended samples

Sample Preparation

- Sand with silt, low organics (2%)
- Homogenization of 198 kg sample
- PFOS in sample measured at 0.37 mg/kg (ΣPFAS 0.57 mg/kg)
- Target PFOS at least 1.5 mg/kg to match site conditions
- Spiked sample with PFOS, targeting 2.5 mg/kg (per Sorengard 2019, using methanol solution)

Solidification

- 5%w/w binder: 50/50 Portland cement & ground granular blast furnace slag (GGBS)
- Mixed, then compacted and hydrated in layers (to emulate construction)

Stabilizers

PRODUCT	GENERIC DESCRIPTION
A	Proprietary powdered bentonite surface-modified clay
B	Proprietary fine-grained aluminum hydroxide, clay and carbon
C	Non-proprietary powdered activated carbon (PAC) (virgin coconut sourced)

A

B

C

LEAF 1314 & SPLP

- 2 controls (w/ and w/out binder)
- 12 mixes (no binder)
- All eluates analyzed for post-TOPA
- T01 and T09 analyzed for pre-TOPA and metals
- Subset of mixes (controls, 0.5% and 2%) analyzed for SPLP

LEAF 1315

- 2 controls (w/ and w/out binder) – same ones as 1314
- 12 mixes (with binder)
- All eluates analyzed for post-TOPA
- T01 and T09 analyzed for pre-TOPA and metals

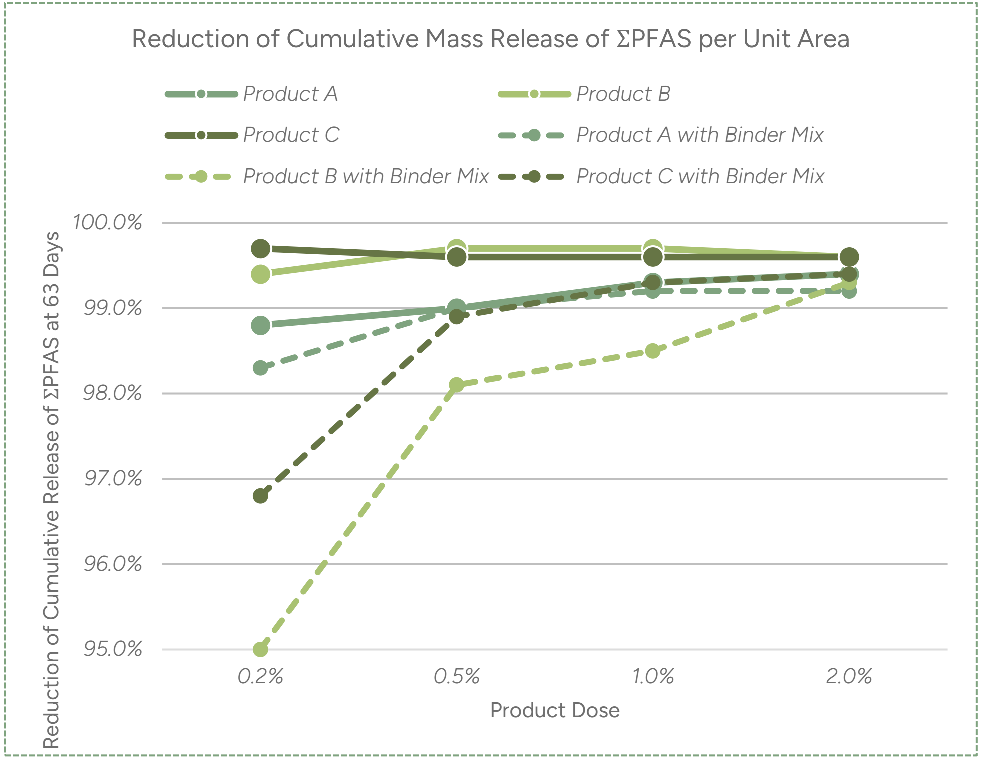
Results & Discussion

Dose Response

Modelled Cumulative Release (all mixes)

Mass Release per unit area basis

- TOPA results (post-oxidation)
- Based on a unit area
- Mass release for 1314 is based on flow cell cross-sectional area
- Mass release for 1315 is modeled based on total submerged surface area of sample monolith
- 1314 results extrapolated to 63 days for comparability to 1315 on a mass release per unit area basis

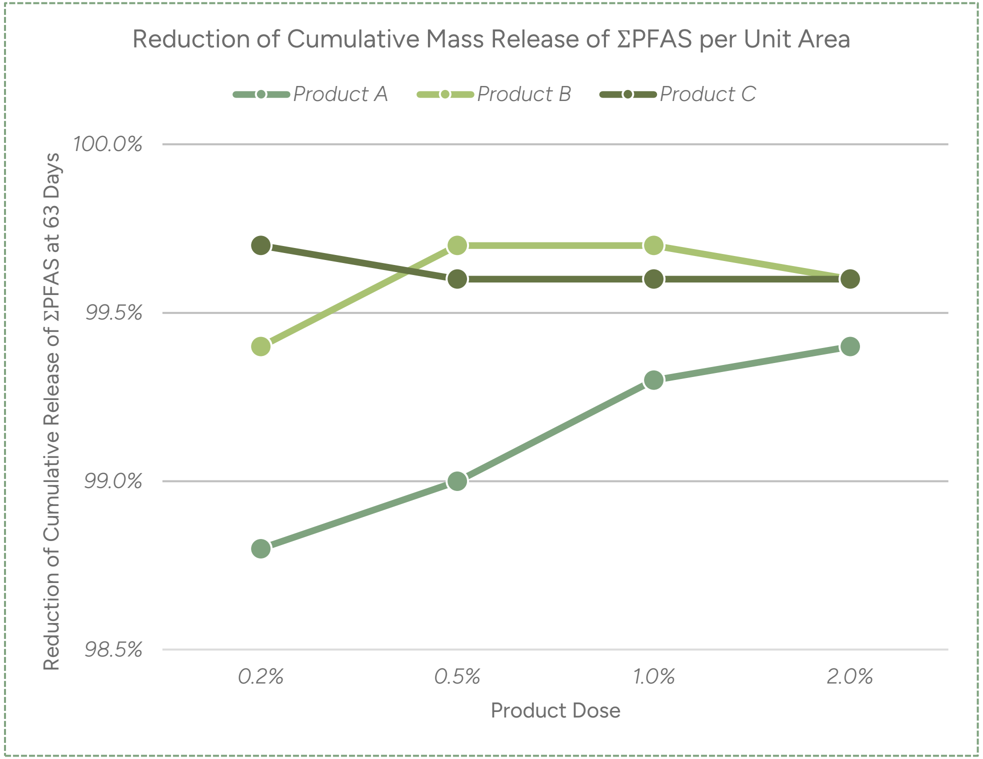


Dose Response

Modelled Cumulative Release (no binder)

Mass Release per unit area basis

- TOPA
- >99.0% cumulative release reduction for all amendments at 1% dose
- Product C outcome appears least sensitive to dose
- Product A not retaining precursors as well (comparing to pre-TOPA)

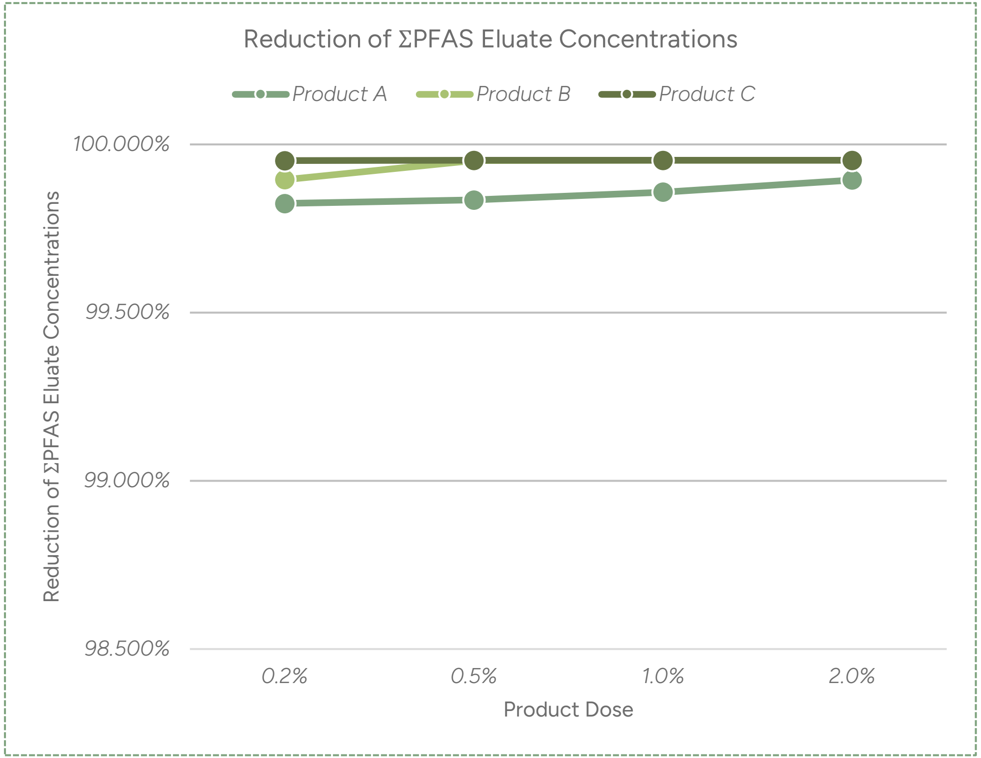


Dose Response

TOPA Eluate Concentrations (no binder)

@ 0.2 L/S Ratio (T01)

- First time point
- early worst-case performance (highest concentration gradient, lowest dilution)
- Very high removal efficiency for all mixes and doses (>99.8%)
- Product C outcome still appears least sensitive to dose
- Maximum TOPA PFOS in amended sample eluate: 0.90 µg/L (Product B @ 0.2%)

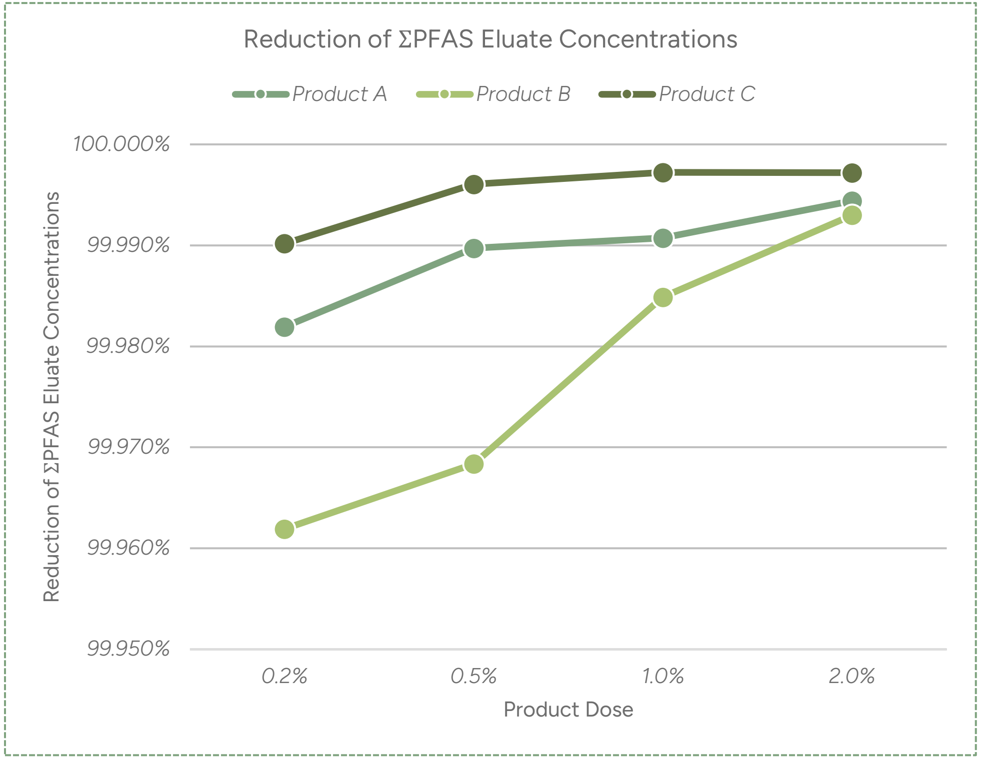


Dose Response

PFAS Eluate Concentrations (no binder)

@ 0.2 L/S Ratio (T01)

- First time point (pre-TOPA)
- reductions may appear higher because of unquantified PFAS
- Dose response more apparent with lower detection limits
- Product C outcome is still least sensitive to dose
- At >99.9% removal, we run up against detection limits (only PFOS is detected)
- Maximum pre-TOPA in amended sample eluate
  - PFOS 0.52 µg/L
  - ΣPFAS 0.87 µg/L.

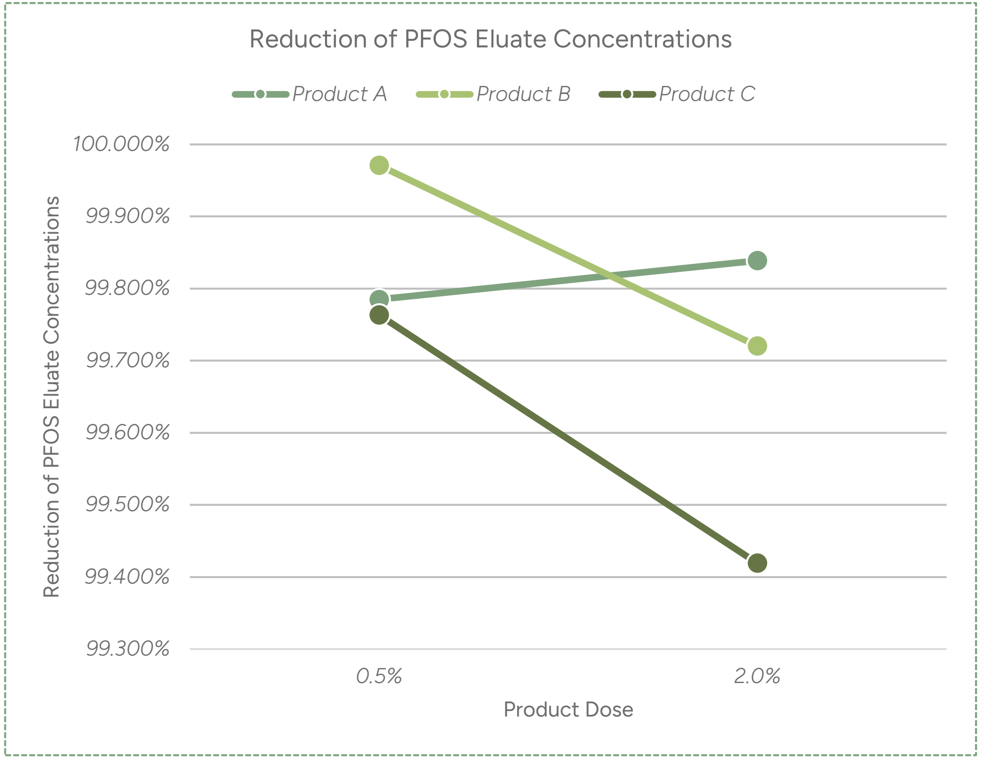


Dose Response

PFAS Eluate Concentrations

SPLP PFOS

- Only 2 mixes assessed for SPLP
- >99.4% reduction relative to control
- 93 µg/L PFOS (control) vs 0.027-**0.54** µg/L (amended): 2-3 orders of magnitude reduction
- Apparent small performance decrease at 2% dose with Products B & C

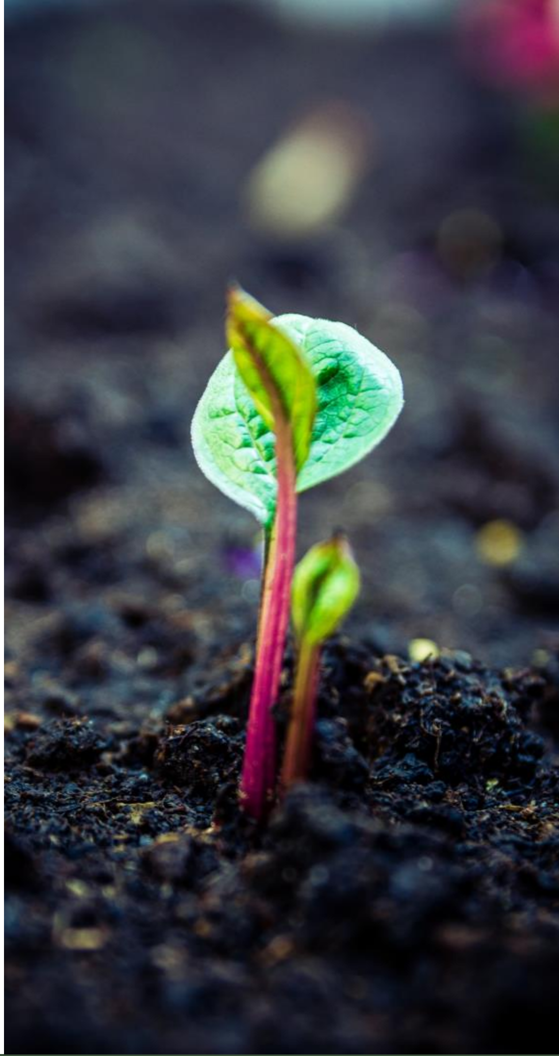


Conclusions

OBJECTIVE	CONCLUSION
1. Relative amendment performance	Good performance from all products
2. Amendment dosing requirements	Lowest dose of 0.2% sufficient for best performer 1%-2% dosing appropriate if specific amendment unknown
3. Performance with binders added (e.g., Portland cement)	Amendment performance decreased but was still adequate at >1% doses.
4. Proxy measurement options	SPLP could provide conservative/timely data, Geotech analysis and hydraulic conductivity not useful as proxies
5. Application to other sites	Risk analysis to include comparison of PFAS concentrations; soil type (i.e., mixing efficacy)

Additional Comments | Next Steps

- Direct use of dose response curves requires objectives focused on improvement rather than meeting a specific reduction.
- Further study is justified if PFAS concentrations vary significantly from the study, soil matrix types vary (e.g., clayey silts) and if SPLP is proposed as contract metric.
- Long term assessment of stabilized soils should include periodic analysis to assess ongoing efficacy and impacts associated with weathering and site use.



Do you have any questions?

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