REMTECH Europe

Remtech Europe – Session 24

Immobilisation: a viable solution for large volumes of diffuse PFAS contaminated soil at Airports

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ADE CONSULTING GROUP

21-09-2023

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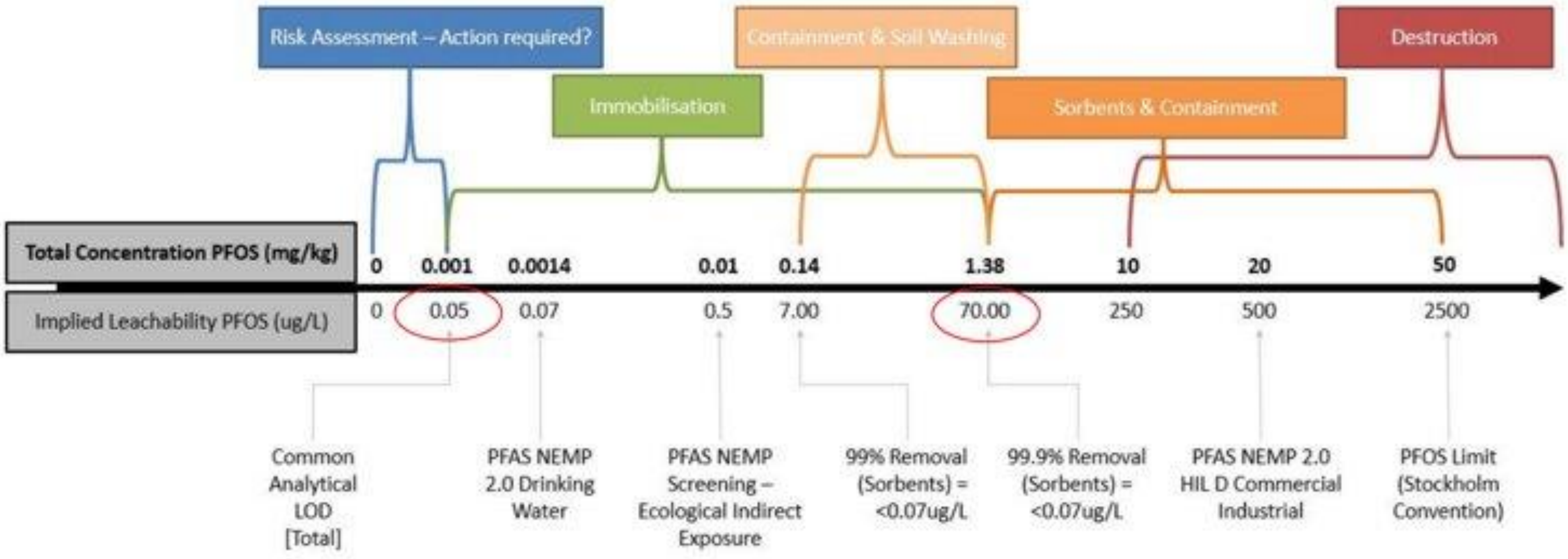
1. Project Objective and Overview

- PFAS contamination at airports is widespread and typically represented by two key modes, source zone contamination and more diffuse contamination broadly spread across airport sites.
- The larger proportion of PFAS mass is in the source zone soils, with the diffuse impacted soil represented by a significant volume of material capable of delivering a sustained PFAS mass flow to receptors.
- A sustainable approach is needed to manage high volumes of relatively low PFAS concentration soils where landfill or thermal options are considered both cost prohibitive and unsustainable.
- **Objective:** Utilise a large-scale trial at Melbourne Airport to assess whether immobilisation was a viable alternative for the treatment of large volumes of diffuse PFAS contaminated soil.

2. Why immobilise? – distinct considerations for source and diffuse zones.

	Source Zone	Diffuse Zone
Proportion of PFAS mass (%)	**90**	**10**
Proportion of material volume (%)	**10**	**90**

2. Why immobilise? – suitability amongst other treatment options



Matthew Askeland, ADE, Federal Contaminated Sites National Workshop, 16th November 2021 RPIC.

2. Why immobilize? – benefits as compared to other treatment options

- Drenning et al. (2023) used a probabilistic cost-benefit analysis (CBA) for evaluating PFAS remediation options (monetisation of direct costs and benefits as well as externalities).
- It demonstrated that remediation of PFAS hotspots and bulk material on the rest of site (diffuse zone) present different needs.
- Maximum value was presented where the bulk material is addressed by immobilisation or solidification.

ELSEVIER

Science of The Total Environment

Volume 882, 15 July 2023, 163664

Comparison of PFAS soil remediation alternatives at a civilian airport using cost-benefit analysis

P. Drenning [a], Y. Volchko [a], L. Ahrens [b], L. Rosén [a], T. Söderqvist [c], J. Norrman [a]

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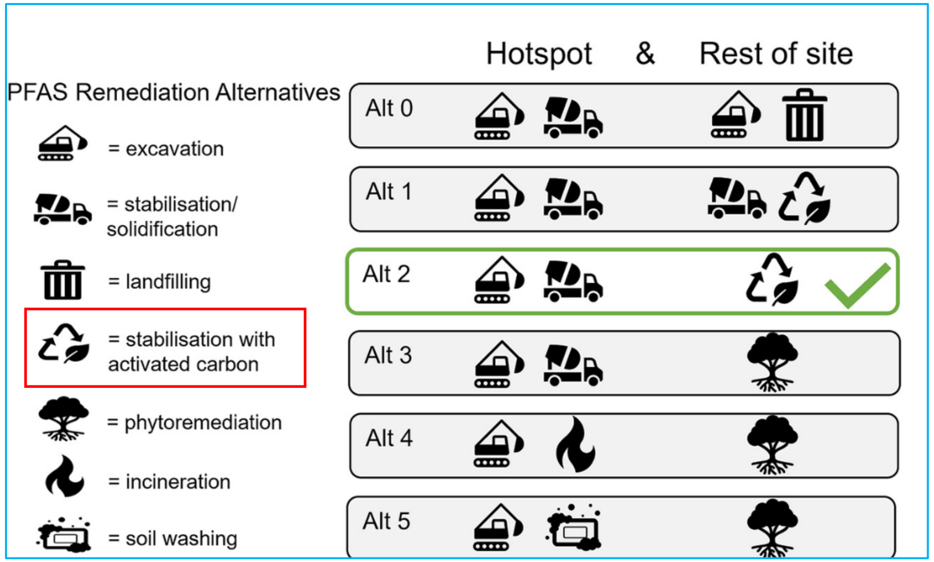
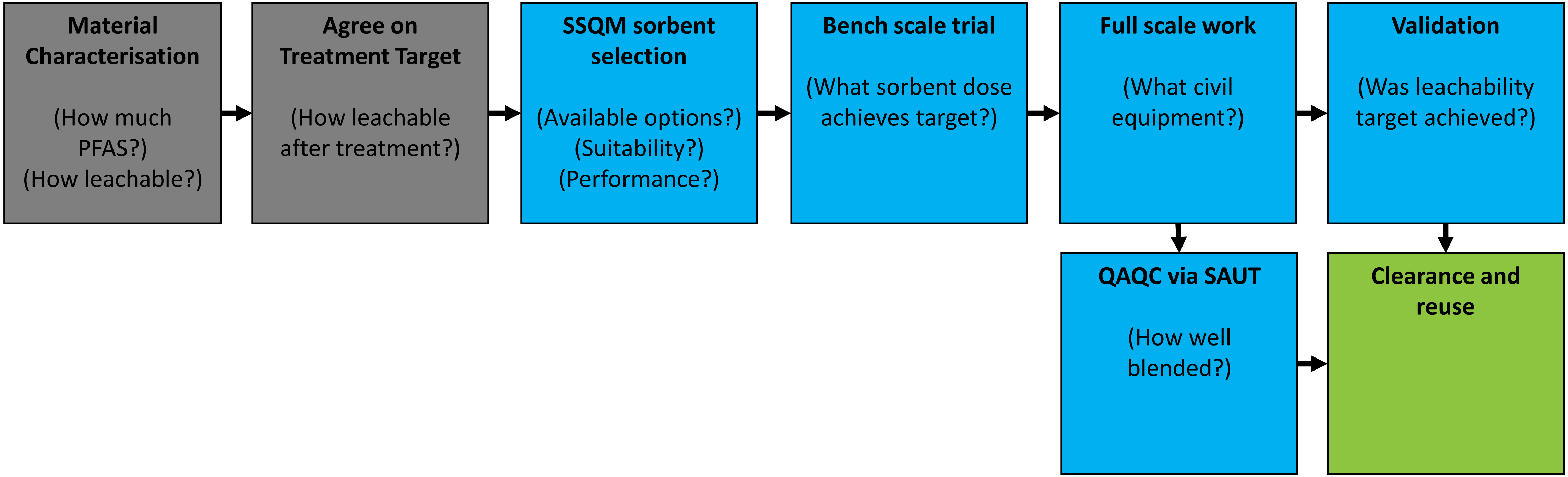


3. Project Process



3. Project Process

Material Characterisation

(How much PFAS?)
(How leachable?)

→

Agree on Treatment Target

(How leachable after treatment?)

→

SSQM sorbent selection

(Available options?)
(Suitability?)
(Performance?)

→

Bench scale trial

(What sorbent dose achieves target?)

→

Full scale work

(What civil equipment?)

→

Validation

(Was leachability target achieved?)

QAQC via SAUT

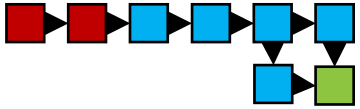
(How well blended?)

→

Clearance and reuse

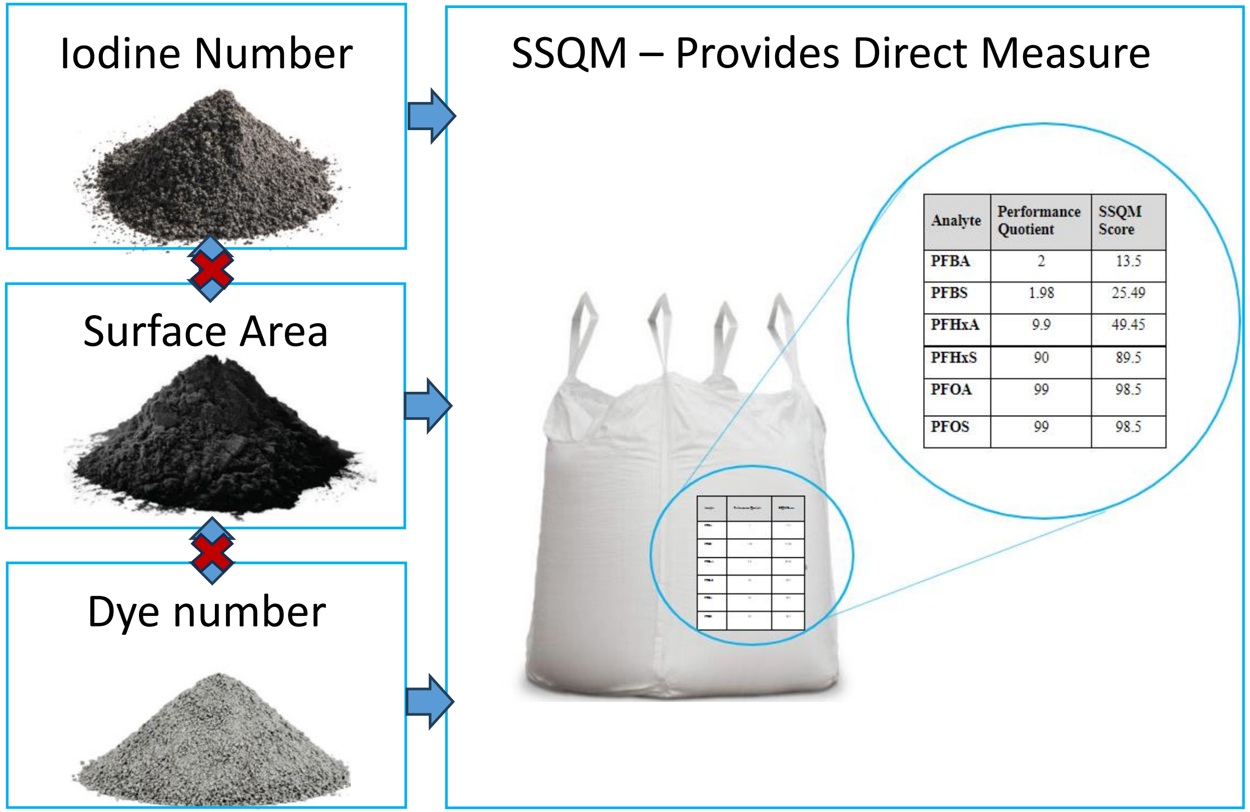
Mean site conditions	PFAS TC	
	Average Total Conc (mg/kg)	Average Leachable (µg/L)
PFOS	0.041	0.640
PFOS + PFHxS	0.047	0.747
Sum of PFAS	0.047	0.751

Reuse Criteria	PFOS + PFHxS Concentration
	µg/L (ASLP pH 7)
Melbourne Airport	≤0.4
Drinking Water	<0.070
DGV Freshwater	<0.0091



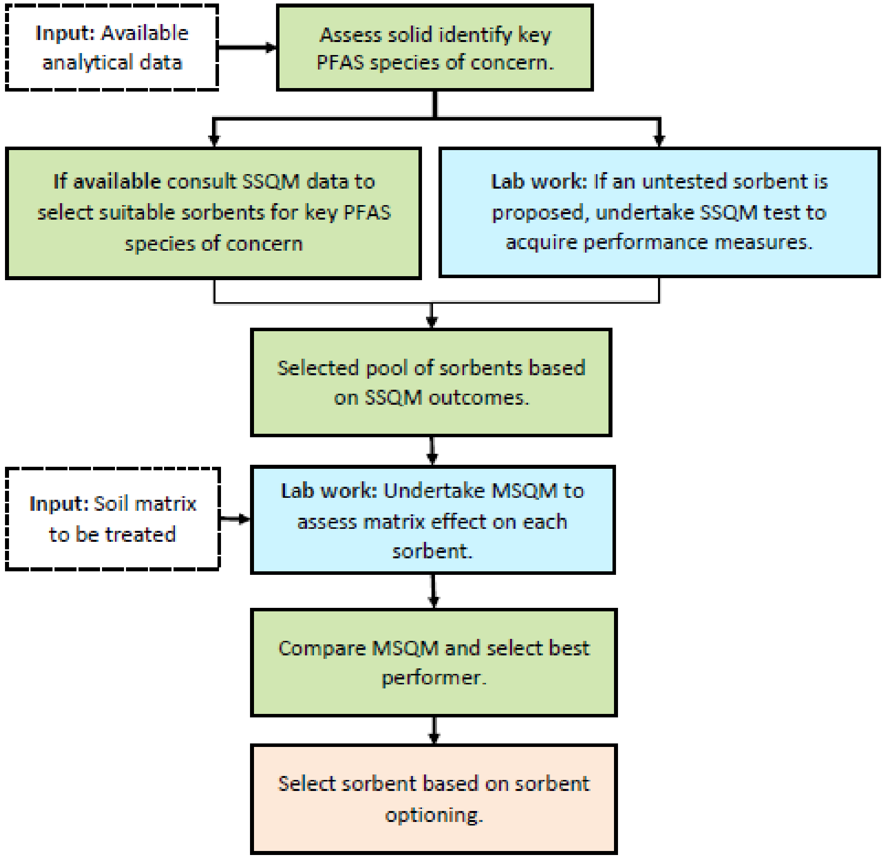
4. Sorbent selection and SSQM

- Standardised Sorbent Quality Measure (SSQM) fills a need for a cross comparable method for selecting a sorbent.
- Considers a range key PFAS species of concern.
- Takes into account matrix effect.
- Suitable for a variety of sorbents

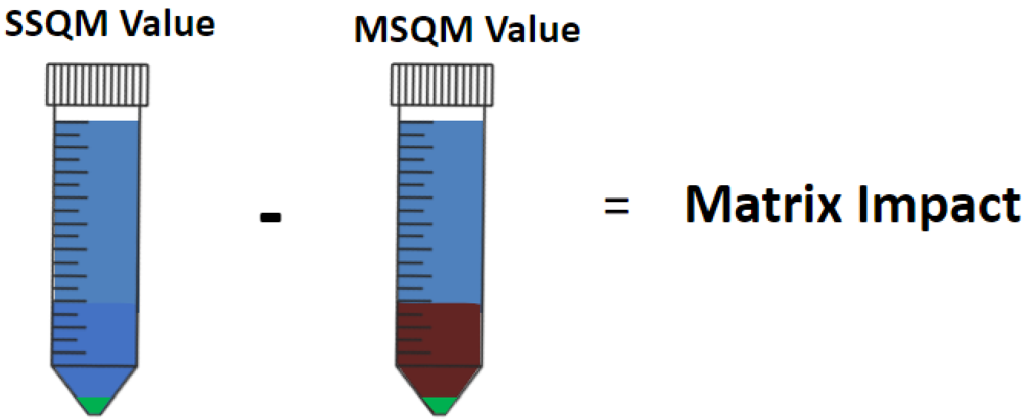


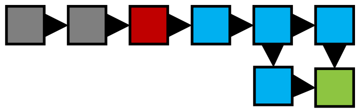
Analyte	Performance Quotient	SSQM Score
PFBA	2	13.5
PFBS	1.98	25.49
PFHxA	9.9	49.45
PFHxS	90	89.5
PFOA	99	98.5
PFOS	99	98.5

4. Sorbent selection and SSQM



- SSQM and MSQM measures performance for PFAS species of interest – **Provides Direct Measure.**
- Makes use of sequential standardised 24-hour sorb and desorb step for 6 PFAS species.



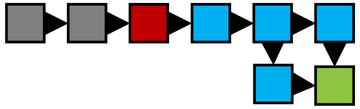


4. Sorbent selection and SSQM

- 16 sorbents and a control tested with SSQM in duplicate.
- 2 sorbents progressed to sorbent-matrix quality testing (MSQM)and control testing.
- Both selected sorbents performed similarly.
- RemBind 100 selected from the two sorbents based on cost and merit (literature available on that specific product).

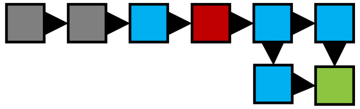
SSQM Output	Percentage Sorbed (%)	Percentage Desorbed (%)	Performance Quotient	Net Removal (%)	SSQM Score
F-100A	43	2.0	39	76	58
F-100B	41	2.0	28	80	54
F-400A	99	1.0	98	97	98
F-400B	83	2.0	43	84	64
PS900A	99	1.0	100	99	100
PS900B	99	1.0	100	99	100
PS1300A	99	1.0	100	99	100
PS1300B	99	1.0	100	99	100
R100A	99	1.0	100	99	100
R100B	99	1.0	100	99	100
S1A	53	12.0	33	97	65
S1B	49	13.0	25	96	61

MSQM Output	Percentage Sorbed (%)	Percentage Desorbed (%)	Performance Quotient	Net Removal (%)	MSQM Score
RB100 + Soil	100	1	100	99	100
PAC13 + Soil	100	1	100	99	100



5. Bench scale trial

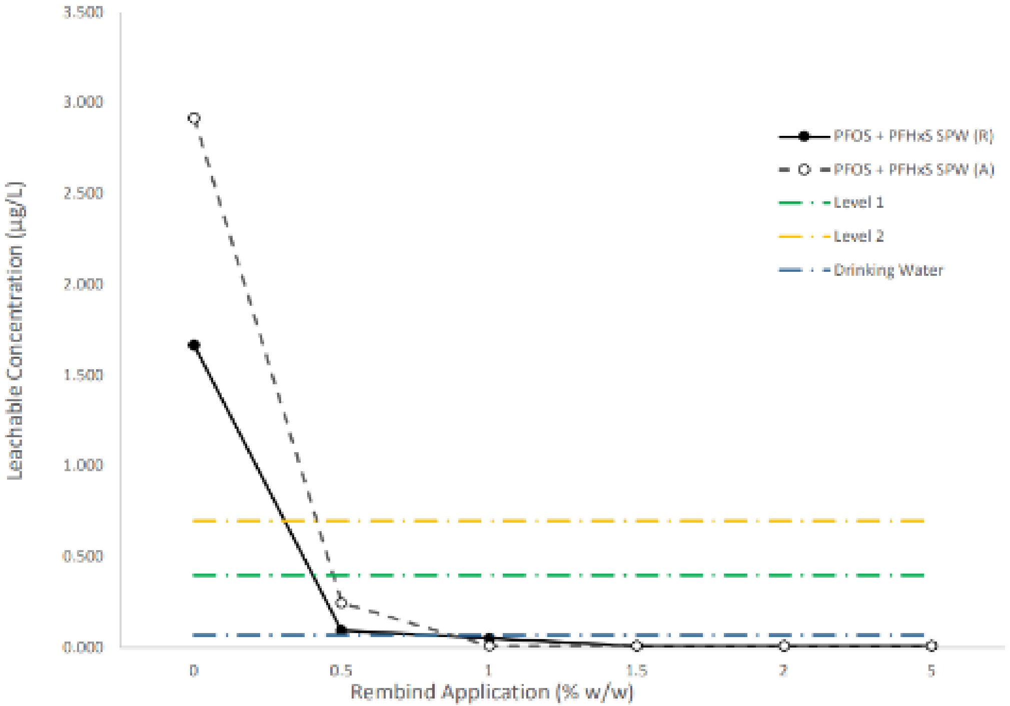
- Adequate number of samples collected from each bulk stockpile for characterisation.
- Stockpile SPW and SPS selected for trial and amalgamated.
- Soil dosed at 0, 0.5, 1, 1.5, 2, and 5% w/w RemBind.
- Academic and realistic method used to assess sample preparation and blending method impact on specification.
- Soils analysed for PFAS leachability at pH 5 and pH 7.



5. Bench scale trial

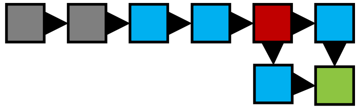
Stockpiles		Average Total Concentration		Average Leachable Fraction at pH 5		Average Leachable Fraction at pH 7	
RemBind Application Approach	RemBind Dose (%)	PFHxS + PFOS (mg/kg)	Standard Deviation	PFHxS + PFOS (µg/L)	Standard Deviation	PFHxS + PFOS (µg/L)	Standard Deviation
SPW (Realistic)	0	0.0513	0.005	1.390	0.349	1.668	0.565
	0.5	0.0117	0.004	0.010*	0.111	0.093	0.059
	1	0.0035	0.001	0.010	0.000	0.052	0.059
	1.5	0.0028	0.003	0.010	0.000	0.010	0.000
	2.0	0.0018	0.000	0.010	0.000	0.010	0.000
	5	0.0017	0.001	0.010	0.000	0.010	0.000
SPW (Academic)	0	0.0897	0.015	1.403	0.266	2.917	0.324
	0.5	0.0635*	0.031	0.078*	0.110	0.247	0.240
	1	0.0267	0.009	0.062	0.034	0.010*	38.72
	1.5	0.0143	0.002	0.053	0.027	0.010*	0.054
	2.0	0.0140	0.006	0.060	0.012	0.010	0.000
	5	0.0055*	0.091	0.022	0.009	0.010	0.000
SPS (Realistic)	0	0.0417	0.004	1.003	0.647	1.233	0.488
	0.5	0.0073	0.002	0.010	0.000	0.010	0.000
	1	0.0032	0.000	0.010	0.000	0.010	0.000
	1.5	0.0028	0.000	0.010	0.000	0.010	0.000
	2.0	0.0015	0.000	0.010	0.000	0.010	0.000
	5	0.0017	0.001	0.010	0.000	0.010	0.000
SPS (Academic)	0	0.0530	0.001	0.062	0.012	1.223	0.316
	0.5	0.0233	0.001	0.010	0.000	0.010	0.000
	1	0.0200	0.005	0.010	0.000	0.010	0.000
	1.5	0.0210	0.016	0.010*	1.636	0.010	0.000
	2.0	0.0100	0.004	0.010	0.000	0.032*	0.031
	5	0.0043	0.000	0.010	0.000	0.010	0.000

Notes:
APAM Level 1 Soil, APAM Level 2 Soil, APAM Level 3 Soil, APAM Level 4, APAM Level 5 Soil
* The calculation of this value excluded true outliers that were clearly erroneous or not representative of the of the other replicates in the data group.



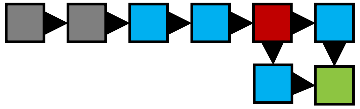
6. Immobilisation Methodology

- Soil treatment involved the addition of 1-2% RemBind® to 8000 tons of stockpiled soil.
- Three different blending methods to assess their ability to apply the sorbent evenly and efficiently; an excavator with sieve bucket, a pug mill, a portable trommel screen.
- Two treatment approaches, “single pass blend and dose”, as well as a “double pass” dose and blend then a second blend.
- Over 24 stockpiles of 100 – 2000 tons each included in testing factorial and treated in the trial.



6. Immobilisation Methodology

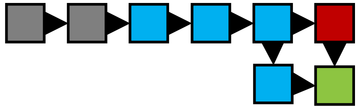
- Each stockpile characterised pre- and post- treatment.
- Post treatment characterisation undertaken 24 hours after treatment.
- In total, more than 500 soil samples were collected from 24 stockpiles including 50 QAQC samples to enable high resolution assessment.
- The Sorbent Application Uniformity Test (SAUT) was used to assess the accuracy and precision of the mixing processes by assessing the distribution throughout the material.



7. Immobilisation outcomes

- Validation demonstrated PFAS leachability was reduced from Sum PFAS ranging from 0.052 -2.346 µg/L to less than the limit of detection (0.001 µg/L).
- PFAS leachability reduction was noted for shorter (where present) as well as long chain congeners.
- The reduction in leachable fractions for PFOS + PFHxS was found to be >99 % in treated soils.

Stockpile	PFAS Congeners	Leachable Fraction Pre -Treatment (µg/L)	Leachable Fraction Post -Treatment (µg/L)	Immobilised (%)
Excavator Blended Stockpiles				
1%-E-E1 (ST-P1)	PFOS + PFHxS	1.077	(<LOD)	~100
1%-E-E2 (ST-P2)	PFOS + PFHxS	0.065	(<LOD)	~100
1%-E-E3 (ST-P3)	PFOS + PFHxS	1.901	0.023	98.79
1%-E-B (ST-BE2)	PFOS + PFHxS	0.707	(<LOD)	~100
2%-E-E1 (ST-P4)	PFOS + PFHxS	1.464	(<LOD)	~100
2%-E-E2 (ST-P5)	PFOS + PFHxS	0.385	(<LOD)	~100
2%-E-E3 (ST-P6)	PFOS + PFHxS	0.989	(<LOD)	~100
2%-E-B (ST-BE1)	PFOS + PFHxS	1.035	(<LOD)	~100
Pugmill Blended Stockpiles				
1%-P-E1 (ST-E1)	PFOS + PFHxS	1.439	0.007	99.51
1%-P-E2 (ST-E2)	PFOS + PFHxS	0.554	0.001	99.82
1%-P-E3 (ST-E3)	PFOS + PFHxS	0.639	0.001	99.63
1%-P-B (ST-BP1)	PFOS + PFHxS	0.887	(<LOD)	~100
2%-P-E1 (ST-E4)	PFOS + PFHxS	0.608	(<LOD)	~100
2%-P-E2 (ST-E5)	PFOS + PFHxS	1.318	(<LOD)	~100
2%-P-E3 (ST-E6)	PFOS + PFHxS	0.073	(<LOD)	~100
2%-P-B (ST-BP2)	PFOS + PFHxS	1.541	(<LOD)	~100
Trommel Blended Stockpiles				
1%-T-E1 (ST-T4)	PFOS + PFHxS	0.138	(<LOD)	~100
1%-T-E2 (ST-T5)	PFOS + PFHxS	0.174	(<LOD)	~100
1%-T-E3 (ST-T6)	PFOS + PFHxS	0.648	(<LOD)	~100
1%-T-B (ST-BT2)	PFOS + PFHxS	0.390	(<LOD)	~100
2%-T-E1(ST-T3)	PFOS + PFHxS	0.139	(<LOD)	~100
2%-T-E2 (ST-T2)	PFOS + PFHxS	0.137	(<LOD)	~100
2%-T-E3 (ST-T1)	PFOS + PFHxS	0.130	(<LOD)	~100
2%-T-B (ST-BT1)	PFOS + PFHxS	0.025	(<LOD)	~100



7. Immobilisation outcomes

- Reuse target of below 0.4 µg/L PFOS + PFHxS achieved.
- Retrospectively, all results below drinking water criteria (0.070 µg/L).
- All but 1 outcome below Australian Draft PFOS Default Guideline Value for Freshwater ecosystems (9.1 ng/L), assessed here as PFOS + PFHxS due to comparable toxicological profiles.

Stockpile	PFAS Congeners	Leachable Fraction Pre -Treatment (µg/L)	Leachable Fraction Post -Treatment (µg/L)	Immobilised (%)
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1%-P-E1 (ST-E1)	PFOS + PFHxS	1.439	0.007	99.51
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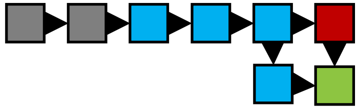
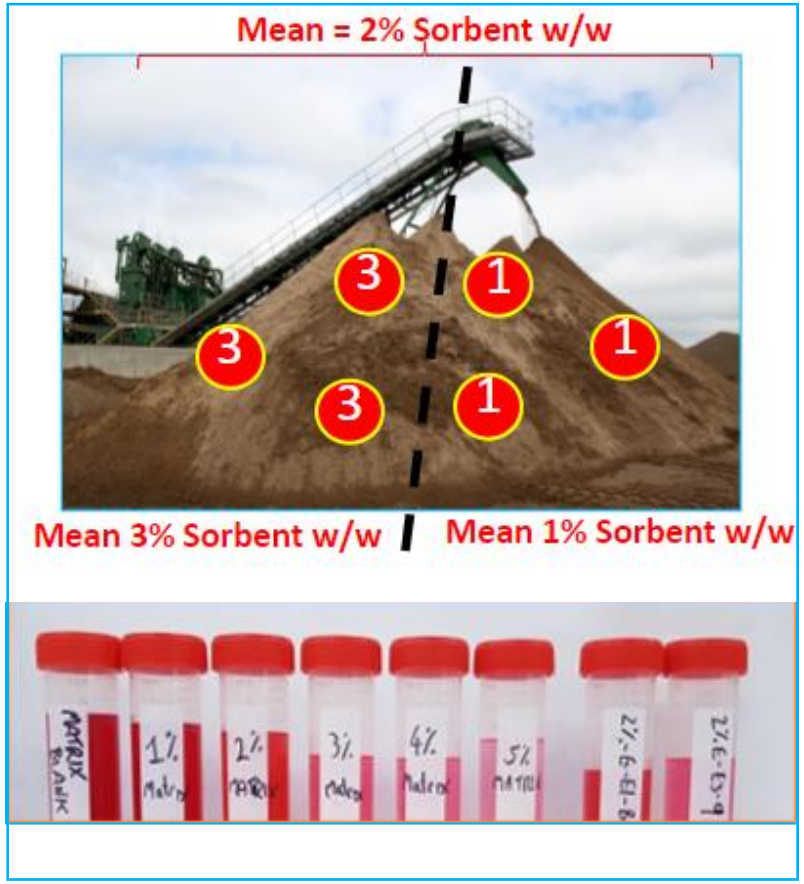
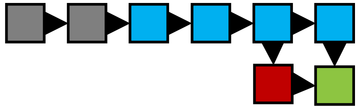


8. Quality control – SAUT

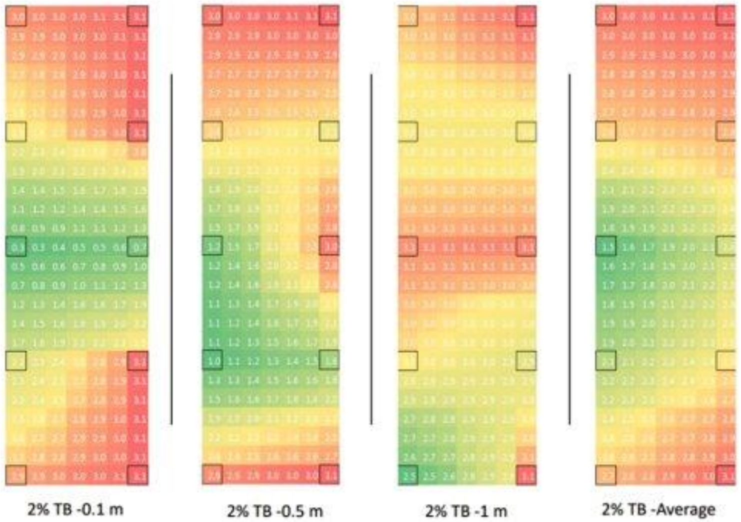
- Dye based method, uses a matrix corrected calibration curve to quantify the mass of a given sorbent in a soil.
- Used to ensure actual sorbent dose lies within an acceptable range based on the % w/w specification from bench trial.
- Provides quick evidence of success and material treatment uniformity and quality.
- Used at various stages in treatment process for identification of non-conformities and rectification.
- Used alongside leachability testing.





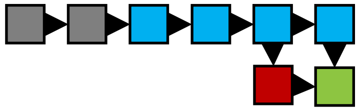
8. Quality control – SAUT

- The SAUT method was found to be suitable as a QA/QC method to be used in tandem with PFAS analysis.
- Demonstrated that adequate sorbent-soil blending was achieved with all of the mixing technologies assessed when considered alongside ASLP results
- Trommel producing the most uniform and accurate blends.



Mixing Equipment	Mean Actual RemBind (%)	Mean Accuracy (%)	Uniformity - RSD (%)	Blend Quality
1% RemBind Specified Application				
Excavator (E)	0.35	35.05	67.13	Unacceptable*
Pugmill (P)	0.86	86.43	69.52	Acceptable
Trommel (T)	1.23	122.68	51.09	Good
2% RemBind Specified Application				
Excavator (E)	1.21	60.50	85.31	Acceptable
Pugmill (P)	0.67	33.70	100.08	Unacceptable*
Trommel (T)	2.58	128.76	30.63	Good

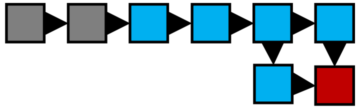
Note to Table: * represents data that demonstrates loss of sorbent fraction as dust that biased the methodology, in that blending was found by SAUT to be low quality but PFAS leachability testing demonstrated a satisfactory result.



9. Project Outcomes

- Soil successfully treated to reduce PFAS leachability to below target airport reuse requirements.
- Scalability demonstrated through use of different scales of soil blending equipment.
- Soil able to be processed at a high throughput rate (~1000 - 1500 ton per day).
- A robust QAQC method suitable for identification of treatment non-conformity.
- Robust end-to-end immobilisation approach demonstrated for PFAS impacted spoil management and reuse.

- **Application on future infrastructure projects:**
  - Minimises waste and cost.
  - Maximises sustainability.
  - Allows higher concentration material to be targeted for destruction (value).
  - Can have significant benefits for program (removes disposal limitations).



10. Conclusion

The large-scale pilot trial demonstrated that immobilisation with 1% to 2% RemBind® sorbent is a viable, scalable, sustainable, and cost-effective solution for the treatment of diffuse PFAS contaminated soil at airport sites.

The reductions in PFAS leachability achieved by the treatment process were adequate to enable the sustainable reuse of the soils at the airport site.

The novel validation techniques used to assess the quality of soil blending demonstrated the effectiveness and scalability of the overall treatment process.

ADE CONSULTING GROUP

Special Thanks:

Nick Walker - Australia Pacific Airports Melbourne (APAM),
Dr Richard Stewart – RemBind,
Mubiana Matakala - ADE Consulting Group,
Thomas Hanley and **Nial Finegan -** EDCORP Project Solutions**,**
Alison Price – SoilCyclers.

Thanks to our project partners:

MELBOURNE AIRPORT | RemBind® | EDCORP PROJECT SOLUTIONS

REMTECH Europe

Remtech Europe – Session 24

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