Immobilization and Safe Disposal of Aqueous Film Forming Foam (AFFF) Impacted Soil in Australia

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A Commercial Airport Site in Australia

Aerial view of airport showing Aviation Rescue and Fire Fighting Services (ARFFS) complex

Damaged asphalt apron

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Generation of PFAS Soil

Construction of new apron

PFAS contaminated soil ~900 tonnes

?

PFOS total concentration <5.7 mg/kg
*PFOS leachable concentration <180 µg/L**

** As determined by USEPA Method 1311*

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PFAS Soil Management Options

Options	Advantages	Disadvantages
Onsite reuse, storage or burial	• Low cost • Quick and easy	• Not enough space • Unclear PFAS regulations • Long term liability
Thermal treatment	• Destroy PFAS • Reuse soil	• Portable unit not available • Uneconomical for small volumes
Landfill	• Final solution • Quick and easy • Available locally	• Landfill licence did not allow for PFAS soil disposal • Leachate concerns

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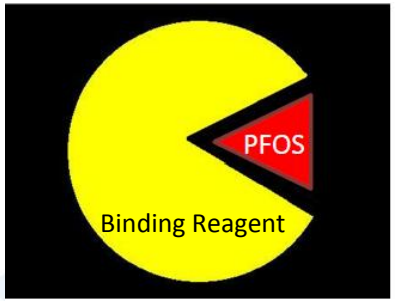
Method of Choice:
Chemical Immobilization → Landfill



- Reduces leachate risk
- Easy and quick to apply
- Conventional machinery
- Cost-effective

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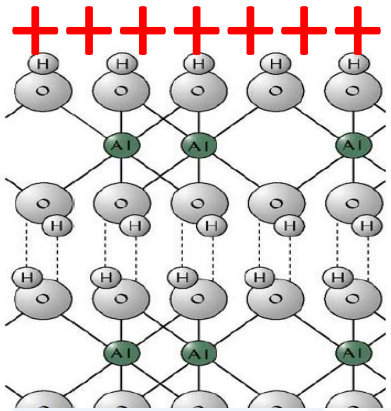
Reagent of Choice – RemBind®

- The airport authority had previously conducted its own testing on the product
- The product had technical credibility having been developed by Ziltek and the CSIRO
- The product had been used commercially to treat PFAS contaminated soil in Australia

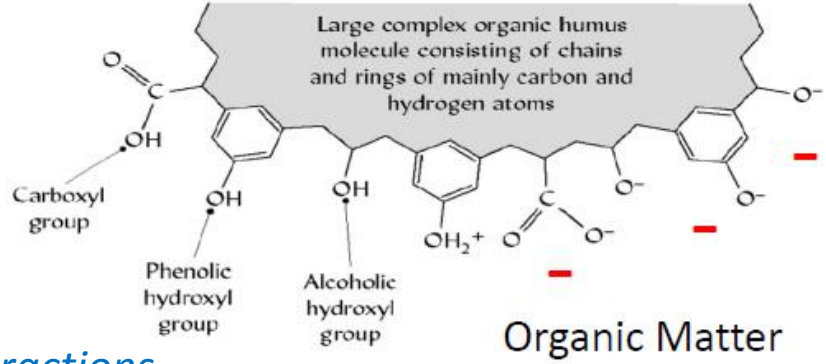
Mechanism of Action - RemBind®

Point of zero charge > pH 9.1



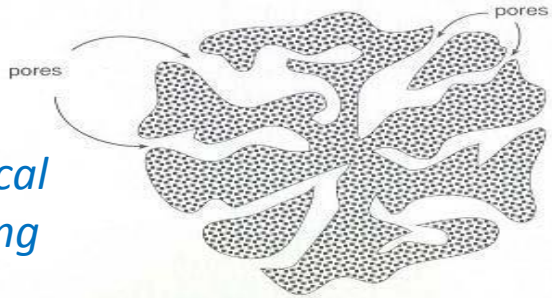
Aluminium Hydroxide
(Amorphous)

Electrostatic Interactions



Organic Matter

Hydrophobic Interactions



Physical Binding

Van der Waals

Activated Carbon

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Bench Scale Trial Results

Table 3: RemBind and RemBind Plus Leaching Results for BH5 and BH11

Location and Treatment	PFOS (µg/L)	PFOS Reduction from control	PFOA (µg/L)	PFOA Reduction from control	6:2 FtS (µg/L)	8:2 FtS (µg/L)
BH5						
Control	120	NA	0.51	NA	<0.1	<0.1
2.5% RB+	0.16	99.9%	<0.02	>96.1%	<0.1	<0.1
7.5% RB+	0.03	99.9%	<0.02	>96.1%	<0.1	<0.1
15% RB+	<0.02	>99.9%	<0.02	>96.1%	<0.1	<0.1
2.5% RB	0.11	99.9%	<0.02	>96.1%	<0.1	<0.1
5% RB	<0.02	99.9%	<0.02	>96.1%	<0.1	<0.1
BH11						
Control	184	NA	1.04	NA	<0.1	<0.1
2.5% RB+	0.20	99.9%	<0.02	>98.1	<0.1	<0.1
7.5% RB+	0.05	99.9%	<0.02	>98.1	<0.1	<0.1
15% RB+	0.03	99.9%	<0.02	>98.1	<0.1	<0.1
5% RB	0.03	99.9%	<0.02	>98.1	<0.1	<0.1

Regulatory criteria adopted = 0.2 µg/L

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Full Scale Soil Treatment

1. Transported 900 tonnes of soil to municipal waste landfill site
2. Treated hotspots with 10% RemBind
3. Validated samples at accredited lab
4. Obtained EPA approval for disposal in a purpose-built burial cell

RemBind being prepared for use

Validation Results

Soil leachate concentrations of PFAS compounds following treatment with 10% RemBind

	Hotspot 1 (µg/L)*	Hotspot 2 (µg/L)*	Compliance Limit (µg/L)*
PFOS	<0.01	<0.01	0.2
PFOA	<0.01	<0.01	
6:2 Fluorotelomer sulfonate	<0.1	<0.1	
8:2 Fluorotelomer sulfonate	<0.2	<0.2	

*Soil leachate concentrations as measured by TCLP at pH 5

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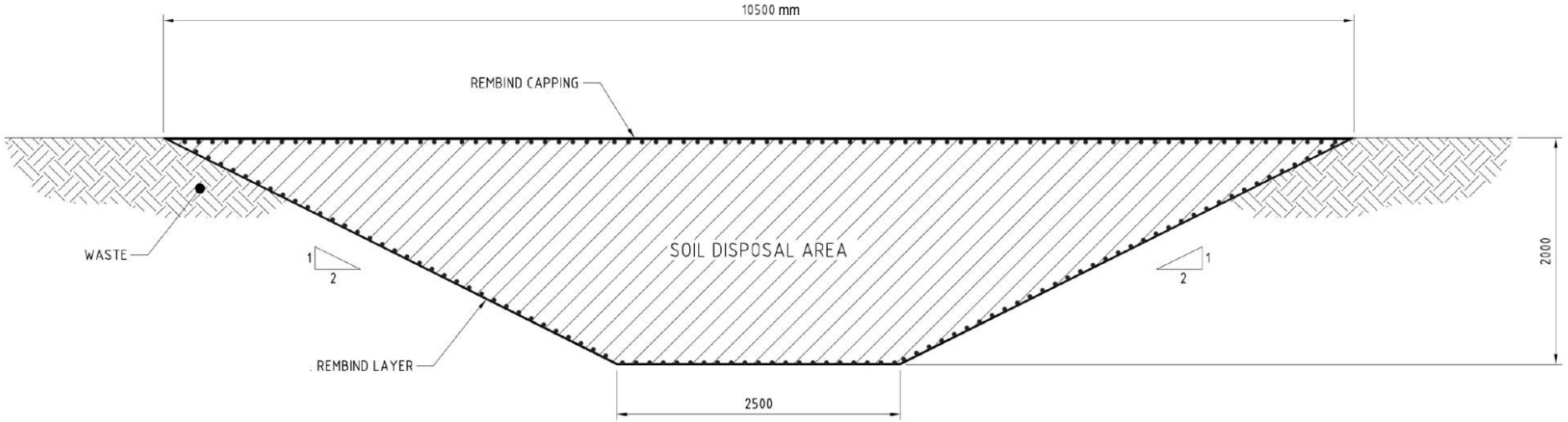
Burial Cell Design



Final Capped Solution

Laying the RemBind capping layer

Finished lined burial cell

Project Cost Summary

Activity	Approximate Cost (USD)	Cost per Tonne (900 Tonnes)
Landfill disposal fees	$59,000	$66
Investigation, bench trials, mixing, and reagent supply	$45,000	$50
Total	**$104,000**	**$116**

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Multiple Extraction Procedure (MEP)

- Based on USEPA Method 1320 and simulates 1,000 years of acid rain conditions in an improperly designed landfill
- RemBind treated PFAS soil passed the MEP test

Example Site 1 - RemBind Treatment										
Leach	EP	1	2	3	4	5	6	7	8	9
PFOS µg/L	0.04	0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
pH	3	5	5	5	5	5	5	5	5	5

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Long Term Stability in Different Soil Types

Site	Soil Type	Product	Product Addition Rate % (w/w)	PFAS Concentrations in Soil Leachates*					Below NSW EPA Landfill Criteria? 50 µg/L**	PFOS Reduction %	Passed USEPA Method 1320?	PFOS/Total PFAS*** %
				Before Treatment			After Treatment					
				PFOS mg/kg	PFOS µg/L	PFOA µg/L	PFOS µg/L	PFOA µg/L				
1	Silty clay loam	RemBind Plus	5.0	0.74	34	0.65	0.29	<0.02	Yes	99.20	Yes	86
2	Silty clay	RemBind Plus	7.5	2.24	376	5.6	0.1	<0.02	Yes	99.97	Yes	67
3	Clay	RemBind Plus	5.0	20.9	695	11	1.5	<0.02	Yes	99.80	nt	99
4	Clayey silt (organic)	RemBind Plus	10.0	3.15	38	1.17	1.9	<0.02	Yes	95.00	Yes	99
5	Sand	RemBind Plus	5.0	1.26	1	1	<0.02	<0.02	Yes	>98.00	nt	99
6	Heavy clay	RemBind Plus	5.0	3.01	87	1.54	<0.02	<0.02	Yes	>99.98	nt	nt
7	Silty sand	RemBind Plus	5.0	7.25	190	0.05	0.05	<0.02	Yes	99.97	Yes	99
8	Clayey loam	RemBind Plus	5.0	1.45	62.5	2.7	<0.02	<0.02	Yes	>99.97	Yes	98
9	Clay/gravel (spill)	RemBind Plus	10.0	184	4,780	222	3.52	0.21	Yes	99.90	Yes	nt
10	Clay/gravel	RemBind Plus	5.0	1.24	72	0.7	0.1	<0.01	Yes	99.90	nt	66
11	Heavy clay	RemBind Plus	5.0	0.67	36	1	0.1	<0.01	Yes	99.70	nt	40
12	Clay	RemBind Plus	5.0	0.78	43	0.6	0.1	<0.01	Yes	99.80	nt	57
13	Silty clay	RemBind Plus	2.5	nt	120	0.51	0.16	<0.02	Yes	99.90	nt	67
14	Silty clay	RemBind Plus	2.5	nt	184	1.84	0.2	<0.02	Yes	99.89	nt	67

* As prepared by TCLP or ASLP at pH 5
** NSW landfill guidelines stipulate a soil leachate criteria of 50 µg/L for PFOS + PFHxS for general solid waste
*** Ratio of total PFOS/total PFAS extended suite (20 analytes) run by Australian Laboratory Services

TCLP = Toxicity Characteristic Leaching Procedure
ASLP = Australian Standard Leaching Procedure
nt = not tested

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Conclusions

- Immobilization with RemBind followed by landfill provided a **quick** and **practical** remediation solution for 900 tonnes of PFAS impacted soil
- Treatment costs = **$50 USD per tonne** of soil
- Soil passed long term stability testing (USEPA 1320)
- Also paves the way for *in situ* applications

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January 2017, Cape Cod, Massachusetts, USA