EX-SITU SOIL WASHING TO REMOVE PFAS ADSORBED TO SOILS FROM SOURCE ZONES

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Acknowledgements

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- Hunter Anderson – ESTCP Liaison, AFCEC
- Eielson Air Force Base: Kristina Smith, Roy Willis, Michael Bose

Agenda

- Soil Washing Overview
- ESTCP Demonstration at Eielson AFB – ER20-5256
  - Design and Process Flow
  - Performance
- Implementation with other Technologies
- Cost analysis

PFAS Standards and Remediation Options

PFAS Standards/Guidance

Region	PFOA	PFOS	PFBS
Alaska DEC - Soil Migrating to Groundwater	1.7 µg/kg	3 µg/kg	NA
USEPA Groundwater Screening	40 ng/L	40 ng/L	600 ng/L
USEPA RSL Direct Contact	130 µg/kg	130 µg/kg	1,900 µg/kg
USEPA soil to groundwater leaching	0.61 µg/kg	0.0378 µg/kg	1.9 µg/kg

Remediation Options

Technology	Cost per Ton
Landfill & transportation	$200 to $400+
Stabilization	$150 to $300+
Thermal Desorption	$300+
Incineration	$350+

Soil Washing

- Three types:
  - Size Separation
  - Size and Density Separation
  - Separation and Chemical Treatment
- Physical separation and desorption to remove contaminants from soil
- Water soluble contaminants transferred to aqueous phase
- Process water treated using GAC and IXR and recycled
- Highly effective for coarse soil
- Tailored to each site depending on soil characteristics and remediation targets

Volume reduction approach - treats coarse fractions and separates fine fractions for treatment or disposal based on stakeholder's risk management objectives

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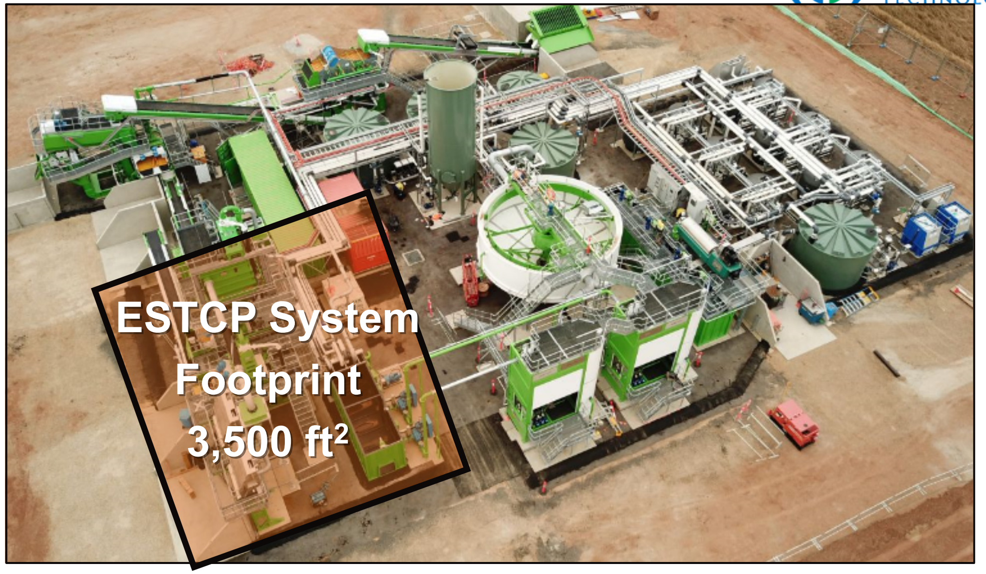
Soil Washing History

- 1980s: Fixed facilities/full scale units used in Europe
- 1980s: USEPA developed mobile soil washing systems
- 1990s: Full scale units used in US for metals
- 2010s: Bench-scale treatment trials for PFAS
- 2018: PFAS fixed facility by Ventia and CET for Australian DoD
- 2021: PFAS mobile unit by Arcadis and CET



Ventia/CET Soil Washing Plant. Edinburgh Air Force Base, Australia. 21,500 ft^2

Arcadis/CET Mobile Soil Washing Plant. Eielson Air Force Base, Alaska. 3,500 ft^2

Volume reduction has been key since 1980s

PFAS Soil Washing

Volume Reduction Approach

- Cost effectively treat coarse-grained soil (gravel and sand)
- Separate fines for secondary treatment:
  - Landfill
  - Stabilization
  - Incineration
  - Thermal Desorption
- Maximizes volume of soil beneficially reused onsite
- Minimizes waste requiring off-site disposal/treatment

Gravel

Sand

Fines

Soil Washing Demonstration
Eielson Air Force Base, Alaska

ESTCP Performance Objectives

Performance Objective	Success Criteria
Bench-scale testing to demonstrate site suitability and optimize treatment process	• >99% removal of PFOS, PFOA, PFBS and >99% removal of sum of 24 PFAS. • Achieve Alaska DEC soil to groundwater clean-up standards for PFOA (1.7 µg/kg), PFOS (3 µg/kg), PFBS (1,900 µg/kg). • Achieve leachate concentrations < USEPA groundwater screening levels: <40 ng/L for PFOA & PFOS, <600 ng/L for PFBS • Post-treatment water concentrations < USEPA HAL
Field-scale trial to demonstrate performance	• >99% removal of PFOS, PFOA, and sum of 24 PFAS • Post-treatment soil concentrations and leachate concentrations less than Alaska DEC and USEPA standards. • Post-treatment water concentrations < USEPA HAL
Cost optimization and reduction of lifecycle costs	• 40 to 50% cost reduction relative to thermal treatment; cost competitive with landfilling

Bench Scale Testing - Soil Washing Eielson Air Force Base, Alaska

Pre-treatment PFAS Concentrations – Pile 393-1

- PFOS is the predominant PFAS,
  - ♦ 85% of Table B-15 PFAS total in soil
  - ♦ 80% of Table B-15 PFAS in leachate
- Previous results indicated PFOS/PFOA concentration of 1,500 ug/kg
  - ♦ concentration 1.7x higher than expected
- Leachate concentrations generally correlated to the totals
- PFOA reported at less than the LOQ at 11 ug/kg, but reported a detectable leachate concentration of 350 ng/L.

PFAS	Stockpile 393-Untreated (393-1-UT)	
	Total (ug/kg)	ASLP (ng/L)
PFOS	2700	32000
PFOA	< 4.2	350
PFBS	6.6 J	230
8:2 FTS	120	1400
PFHxS	98	2500
PFOSA	97	210
PFHxA	40	1400
PFNS	19 J	100
6:2 FTS	19 J	480
PFDS	17 J	100
PFPeA	12 J	460
PFNA	< 4.2	62 J
PFPeS	8.1 J	200
PFHpA	5 J	200
PFUdA	4.6 J	< 25
PFBA	4.6 J	170
PFDoA	4.2 J	< 25
Sum PFAS > DL	3155	39759

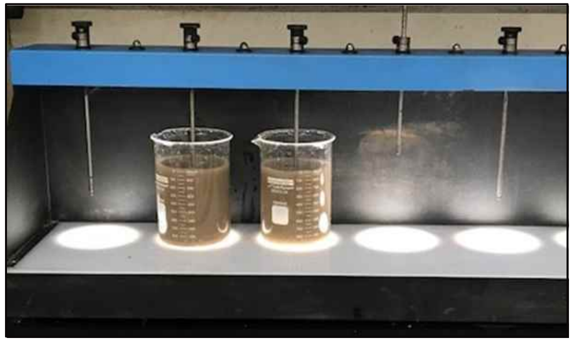
DL = Detection limit
J = Estimated result < LOQ and > DL
ASLP – Australian synthetic leachate procedure

Bench Scale Treatability

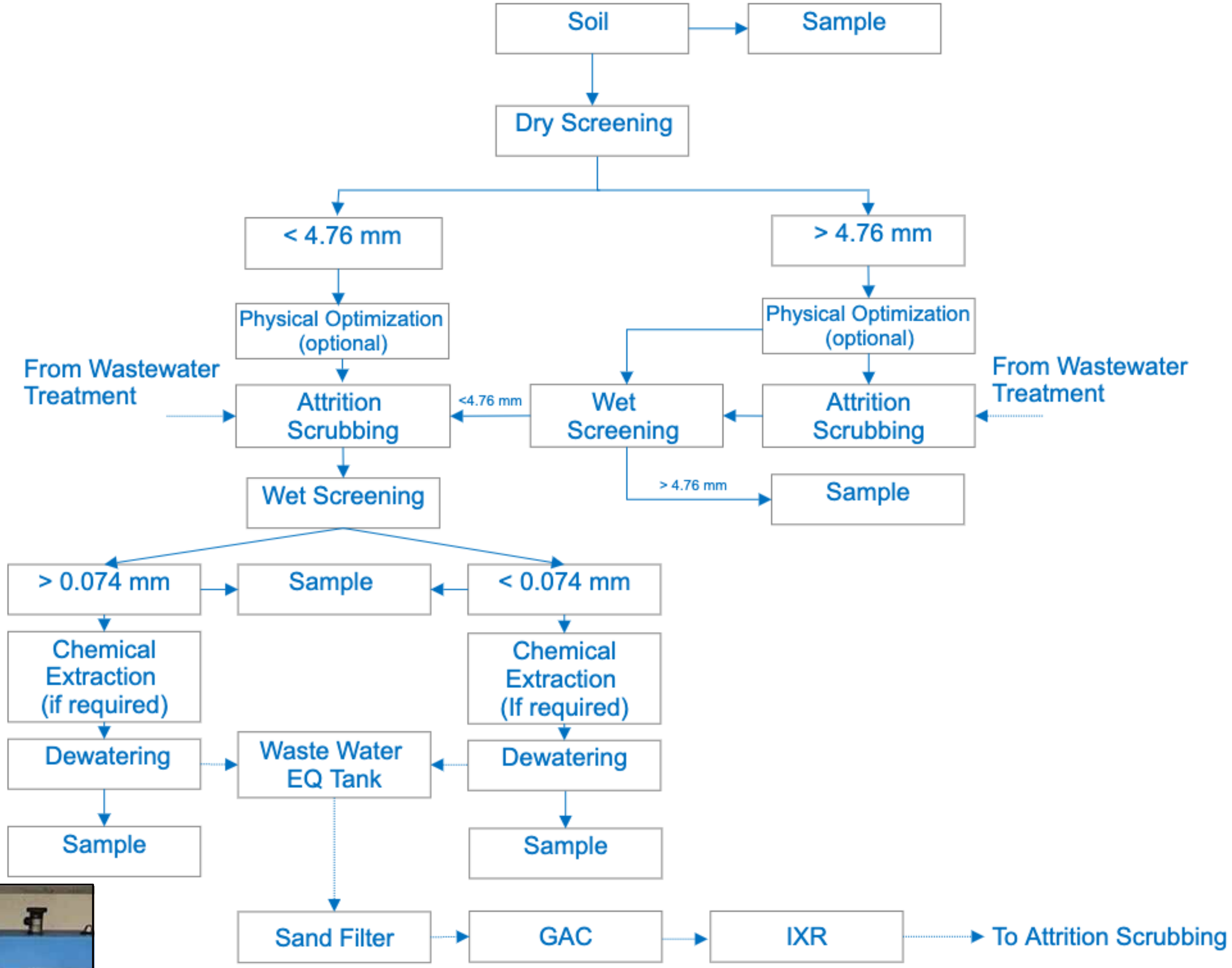
- Evaluate soil characteristics at Eielson AFB
- Three rounds of treatment conducted
- Test PFAS removal under different process conditions:
  - Size separation (screening and scrubbing)
  - Physical Optimization
  - Chemical Extraction

Screening

Attrition Scrubbing



Chemical Extraction



Process flow from bench scale treatability testing

Bench Scale Testing Results: AFFF Source Soil

- Performance objectives achieved using Round 3 process in AFFF Source Soil and Round 1 process in construction soils (15-59 µg/kg)
- Leachate concentrations generally correlated to the totals
- Process water successfully treated using GAC and IXR

Treatment Round	Stockpile EIE393-1 Soil Fraction	PFBS		PFOA		PFOS		Sum PFAS	
		Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L
	Untreated	6.6 J	230	<4.2	350	2,700	32,000	3,155	39,795
Round 1	Rock	<0.2	<10	<0.2	<10	**88**	**200**	97	270
	Gravel	<0.2	<10	<0.2	<10	**27**	**620**	32	803
	Sand	0.26	<10	0.55 J	26 J	**150**	**900**	170	1,005
	Fines	3.1 J	22 J	<3	**53**	**2,400**	**530**	2,822	1,123
Round 2	Rock/Gravel	<0.23	<10	<0.22	<10	**8.8**	**120**	9.4	194
	Sand	<0.19	<10	<0.19	<10	**12**	**75**	14	181
Round 3	Rock/Gravel/Sand	<0.24	<20	<0.24	<20	0.34 J	36 J	0.34 J	36 J
Performance Goals		**1,900**	**40**	**1.7**	**40**	**3**	**40**	**--**	**--**

Full-Scale Demonstration - Soil Washing Eielson Air Force Base, Alaska

Soil Treatment at Eielson AFB

Soil sourced from 3 Stockpiles:

Construction/MilCon Soil

- **EIE382-5** with PFOS 95% UCL concentrations between 70 and 110 ppb
  - 26% fines – typical
  - 40 tons
- **EIE385-4** with PFOS 95% UCL concentration of 29 ppb
  - 23% fines – typical
  - 100 tons

AFFF Source Soil

- **EIE393-1** with PFOS concentrations > 1 ppm
  - Supplemented with soil cuttings from AFFF sources obtained during remedial investigation
  - Highest concentrations/represents AFFF sources
  - 40 tons

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Mobile Treatment Unit

- Minimal site preparation
- 2 sea/cargo containers + water treatment
- Transported via truck, rail or ship
- 60-ton mobile crane
- Powered by generator
- Filled system with water truck ~20,000 gallons
- Entire process could be connected and commissioned in 7 days

Plant Walk Through

Feed Area

- Feed soil into plant

Soil Module 1

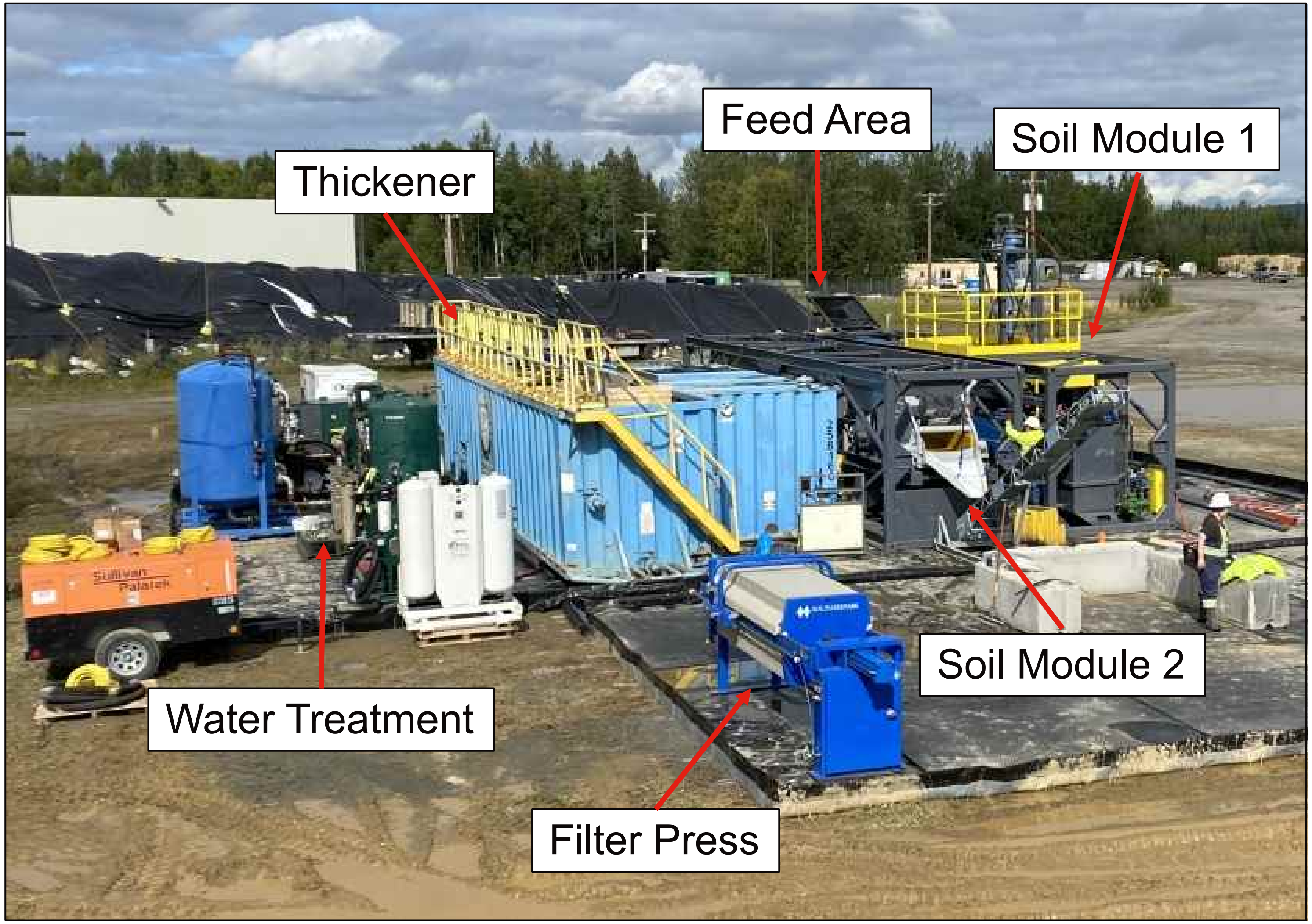
- Add process water
- Gravel separated, dewatered and stockpiled
- Mixing tanks for PFAS desorption
- Separate sand and fines slurry

Soil Module 2

- Attrition scrubbing
- Sand dewatered and stockpiled

Fines and Water Treatment

- Fines slurry sent to thickener, dewatered in filter press and stockpiled
- Process water treated using multimedia filters, GAC, IXR and recycled



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Results – MilCon Soil

- Stockpile concentrations order of magnitude less than expected
- PFBS, PFOA and PFOS concentrations achieved performance goal for coarse soil
- Performance goals achieved for coarse soil using simplest treatment approach
- Fines successfully treated in EIE382-5 (low concentrations)

Stockpile EIE382-5 and EIE385-4 Results

Stockpile	Soil Fraction	PFOS		Sum PFAS	
		Soil µg/kg	RE%	Soil µg/kg	RE%
EIE382-5	Untreated	4.5	--	6	--
	Gravel	<0.23	<DL	0.3	<DL
	Sand	0.2	96.1%	0.2	84.3%
	Fines	1.7	61.8%	2	65.6%
EIE385-4	Untreated	8		16	
	Gravel	0.2	98.1%	0.2	97.9%
	Sand	0.9	88.6%	1.3	92.1%
	Fines	**9**	-7.7%	12	58.8%
Performance Goal		3	--	--	--

AFFF Source Soil Treatment Results

- Round 1 treatment process used
- Round 2 and 3 not implemented due to early freezing conditions
- Performance goals not achieved
- Physical optimization step needed to achieve >99% RE to meet performance goals
- PFAS removal in line with Round 1 bench scale results

Stockpile EIE393-1 Results

Stockpile	Soil Fraction	PFOS		Sum PFAS	
		Soil µg/kg	RE%	Soil µg/kg	RE%
EIE393-1	Untreated	560		675	
	Gravel	**30**	94.6%	**35**	93.0%
	Sand	**31**	94.4%	**38**	95.7%
	Fines	**330**	41.1%	**409**	42.8%
Performance Goal		3	--	--	--

Leachate Results

- PFAS removal corresponded to soil results
- Performance goals achieved for coarse grained soil in EIE382-5 and EOE385-4

Stockpile	Soil Fraction	PFOS		Sum PFAS	
		Leachate ng/L	RE%	Leachate ng/L	RE%
EIE382-5	Untreated	193		316	
	Gravel	<10	<DL	<DL	<DL
	Sand	<10	<DL	50	84.3%
	Fines	56	71.0%	109	65.6%
EIE385-4	Untreated	430		825	
	Gravel	<10	<DL	17	97.9%
	Sand	13	96.9%	66	92.1%
	Fines	243	43.4%	345	58.8%
EIE393-1	Untreated	22000		25833	
	Gravel	1500	93.2%	1796	93.0%
	Sand	840	96.2%	1103	95.7%
	Fines	12667	42.4%	14780	42.8%
Performance Goal		40	--	--	--

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Cost Analysis

Four main cost drivers:

1. **Soil Characteristics:** Grain size and PFAS concentrations

2. **Regulatory Requirements:** Standards are evolving, and lower standards increase treatment costs

3. **Logistics and Residuals Management:** Proximity to landfills, incinerators and thermal facilities

4. **Stakeholder Objectives for Disposition of Residuals:** Is landfilling or destructive treatment required? Or is stabilization and on-site management acceptable?

Cost Matrix for Lower 48

- Scenarios show cost of soil washing to treat coarse grained soil and to separate fines for secondary treatment
- Soil washing cost dependent on cost drivers and range from ~$100-$200/ton. Cost also dependent on % of fines.
- Soil washing is cost effective for soil with up to ~30% fines
- Soil washing soil with 10% fines saves up to 40% compared to landfilling
- Soil washing with thermal desorption is cost-effective up to 30% fines
- Soil washing can add value if sustainability or other metrics are important up to 50% fines

Scenario		**Soil Composition**				
	Fines	5%	10%	20%	30%	50%
	Coarse	95%	90%	80%	70%	50%
Low-Cost $100/ton Soil Washing Coarse $200/ton Landfill Fines		**$110**	**$120**	**$140**	**$160**	$200
Medium-Cost $150/ton Soil Washing Coarse $300/ton Thermal Fines		**$165**	**$180**	**$210**	**$240**	$300
High-Cost $200/ton Soil Washing Coarse $300/ton Thermal Fines		**$215**	**$230**	**$260**	**$290**	$350

- **Bold** values are less than cost of landfilling ($200/ton) for 100% of the soil for the low-cost scenario, or thermal desorption ($300/ton) for 100% of the soil for the medium and high-cost scenarios
- Assumes 25,000 tons of soil for economies of scale tipping the balance toward equipment mobilization vs transportation of soils to centralized disposal/treatment facility

Ongoing research to optimize fines treatment and minimize need for residuals treatment / disposal will improve sustainability and reduce costs

Summary

- Soil washing is a volume reduction technology
  - Treat coarse fractions
  - Separate fines/organics for alternative treatment
- Applicable for AFFF source zones and MilCon soil with low-level impacts
  - Optimize to meet site conditions, treatment objectives and client risk profile
  - Cost competitive with landfilling in lower 48
  - Capable of meeting evolving standards
- Sustainable technology:
  - Onsite treatment reduces trucks on the road
  - Low energy consumption. Focuses destructive treatment on fines/organics

Q&A

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REMEDIATION

THE JOURNAL OF ENVIRONMENTAL CLEANUP COSTS, TECHNOLOGIES, & TECHNIQUES

RESEARCH ARTICLE

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