Passive Abiotic and Biotic Remediation of Chlorinated Solvents



GeoTactical Remediation

Three field case studies
Targeted amendment emplacement

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Introduction

- **Emplacement method**
  - Fracture injection for targeted amendment delivery
- **Three field projects**
  - CDM Smith, Bountiful, Utah: Zero Valent Iron (ZVI) and sand after earlier bioremediation
  - Keystone Environmental Ltd., British Columbia: EHC-L (lecithin + ferrous iron)
  - Wasatch Environmental, Millcreek, Utah: ZVI at the Trillium / Red Hanger site

Site Objectives and Treatment Approach

Site	Site objective	Treatment focus
CDM Smith, Bountiful, Utah	Treat a persistent source hot spot within an existing remedy	Targeted ZVI and sand placement Enhance contact in layered soils
Keystone Environmental Ltd., British Columbia	Address high-risk conditions No redevelopment planned	EHC-L: lecithin + ferrous iron Stimulate the native microbial community
Wasatch Environmental, Millcreek, Utah	Support redevelopment Meet groundwater criteria	ZVI injection in groundwater ZVI soil mixing in shallow sources

Fracture Injection

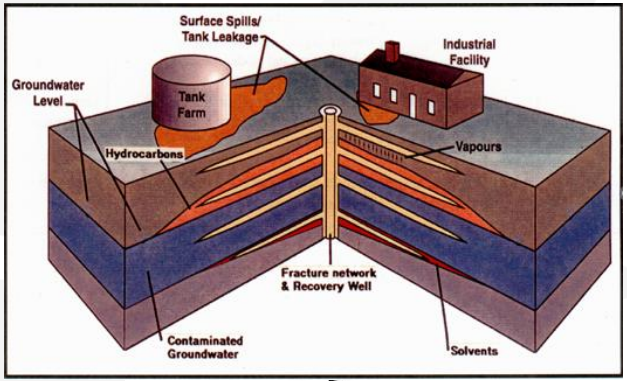
- Pressure induces tensile parting in the target interval
- Slurry carries amendment into the created pathways
- Target selected spacing, depths and intervals

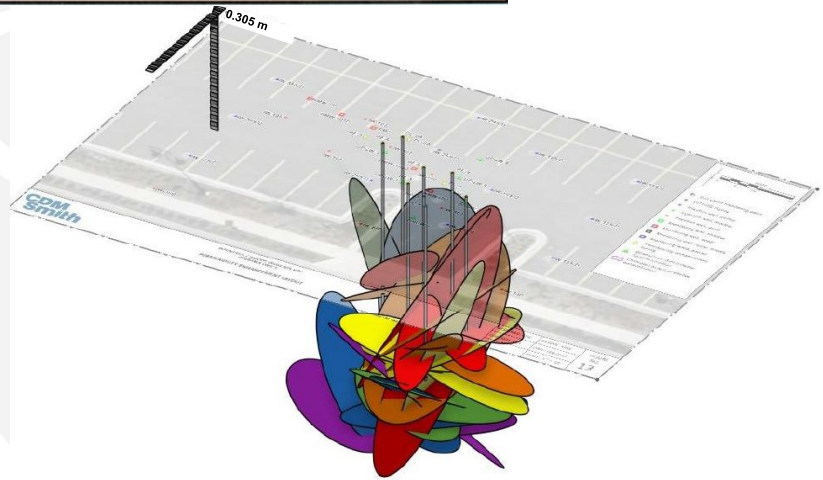




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Amendment Distribution





Target interval selection

Use the contaminant distribution and lithology to select emplacement depths.

Amendment contact

The aim is coverage of the treatment zone. Loading and distribution impact the available reactive contact area.

Fractures

High contact area network

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Abiotic Dechlorination: Iron Options

- **ZVI: metallic iron, Fe(0)**
  - Iron oxidation releases electrons for chemical reduction. Corrosion can also produce Fe(II) and hydrogen
- **Ferrous Fe(II) amendments provide another option**
  - Organo-ferrous compounds and other Fe(II) sources can form reactive minerals, including iron sulfides and magnetite
- **Microbial iron cycling links abiotic and biotic treatment**
  - Microbes use organic carbon to reduce Fe(III) back to Fe(II), renewing reduced iron reactivity (Carbon-Iron Cycling)

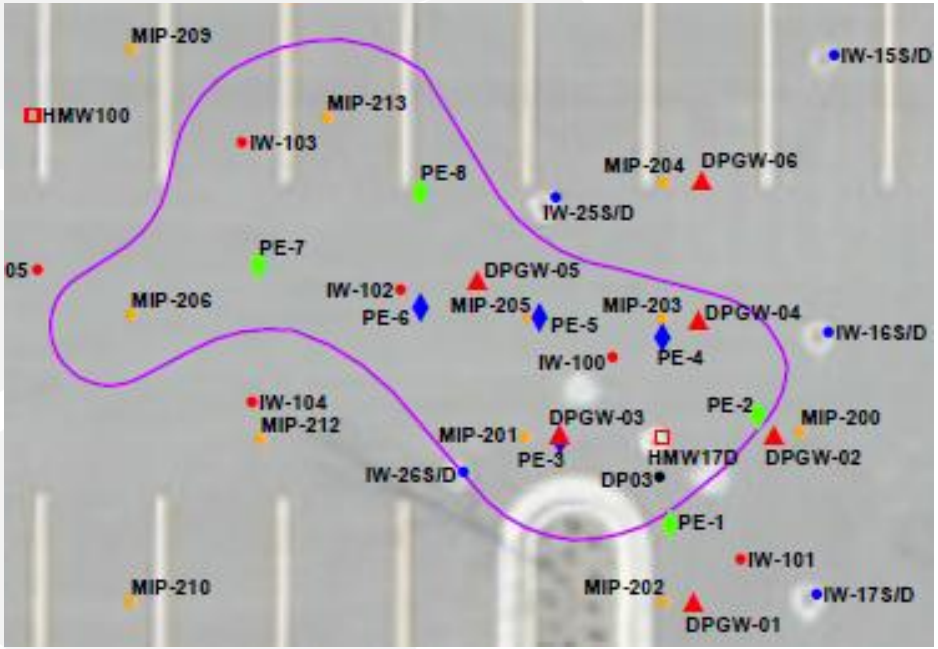
Abiotic Treatment: Selection and Loading

- **Amendment selection and loading designed for site conditions**
  - Account for contaminant demand, competing reactions, longevity and the reactivity of the selected ZVI or Fe(II) material
- **Placement determines contact**
  - A high total mass alone does not establish coverage of the target zone
- **Performance monitoring informs the next treatment stage**
  - Track parent compounds, daughter products and possible rebound

Biotic Dechlorination: The Carbon Donor

- **Microbes need electrons to reduce chlorinated solvents**
  - An electron donor supplies the reducing power needed to replace chlorine with hydrogen
- **Carbon fermentation supplies the donor**
  - Native microbes ferment organic carbon into hydrogen and organic acids. Dechlorinating organisms use the hydrogen
- **Carbon use supports reducing conditions and iron cycling**
  - Microbes consume oxygen and other electron acceptors. Iron reducers can also convert Fe(III) back to Fe(II)

Bountiful: Persistent Source Hot Spot



Existing remedy

A former trucking facility had a residual Trichlororethene (TCE) source and a dissolved plume extending more than 1.6 km.

Remaining challenge

Interbedded sands, silts and clays complicated treatment at HMW-17D after earlier biological treatment.

The 2017 work targeted the remaining source zone.

Bountiful / Woods Cross OU1. CDM Smith presentation, 2018

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Bountiful: Previous Treatment and Driver

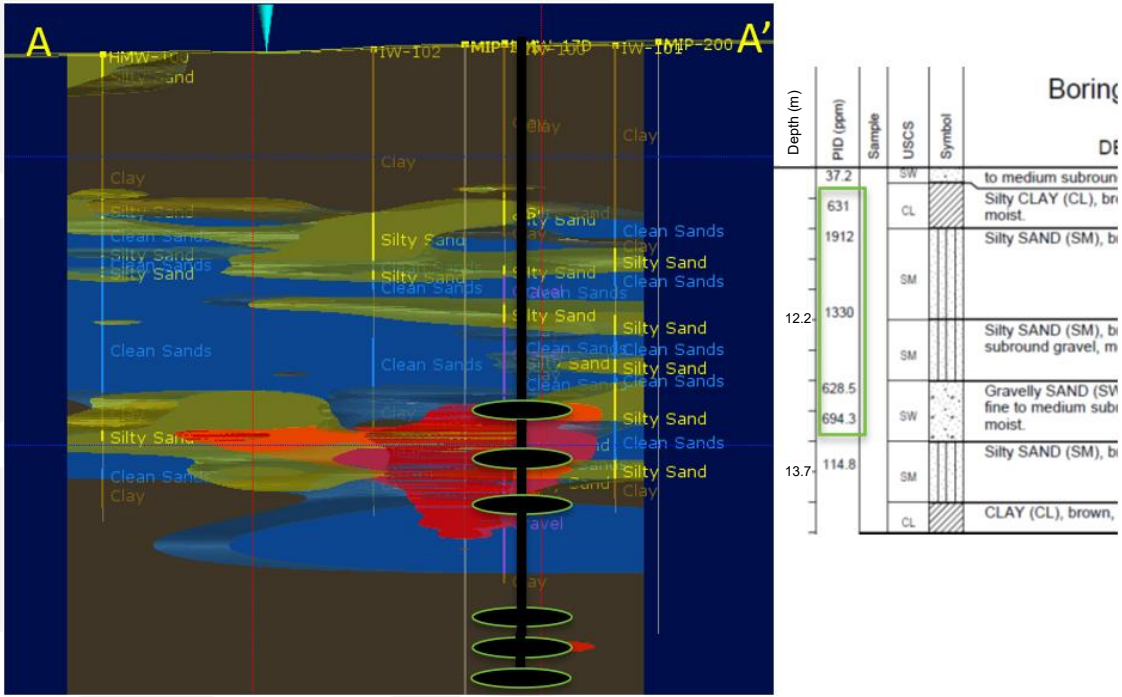
Previous method	Reported response
Emulsified oil EOS / LactOil	Biobarriers and source wells reduced plume concentrations; most of the source approached Maximum Contaminant Levels (MCLs).
Lactate WilClear Plus	At HMW-17D, improved vinyl chloride and ethene production and increased mass transfer.
2014: targeted wells Continued lactate	Further vinyl chloride and ethene production after a second Membrane Interface Probe (MIP) investigation.
2015: electrically induced reduction (EIR) pilot	Increased vinyl chloride and ethene production; further improved mass transfer.

Driver: persistent high concentrations at HMW-17D

In 2016, EPA and the State of Utah sought a more aggressive approach after successive low-cost additions to the remedy. The team selected targeted ZVI and sand emplacement.

Source: CDM Smith, Battelle 2018 presentation, slides 3–8, 10 and 14

Bountiful: Targeted Permeability Enhancement



The team used MIP data and lithology to select injection locations and depths.

Injected sand created higher-permeability lenses.

ZVI supplied reactive material within a dense network of selected intervals.

Closely vertically spaced intervals:
0.6–0.9 m

Source model and treatment approach: CDM Smith presentation, slides 8–15

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Bountiful: ZVI and Sand Emplacement



~ Total 9.1 tonnes each

ZVI and sand

9 injection points

3–6 intervals per point

<5 days

field implementation

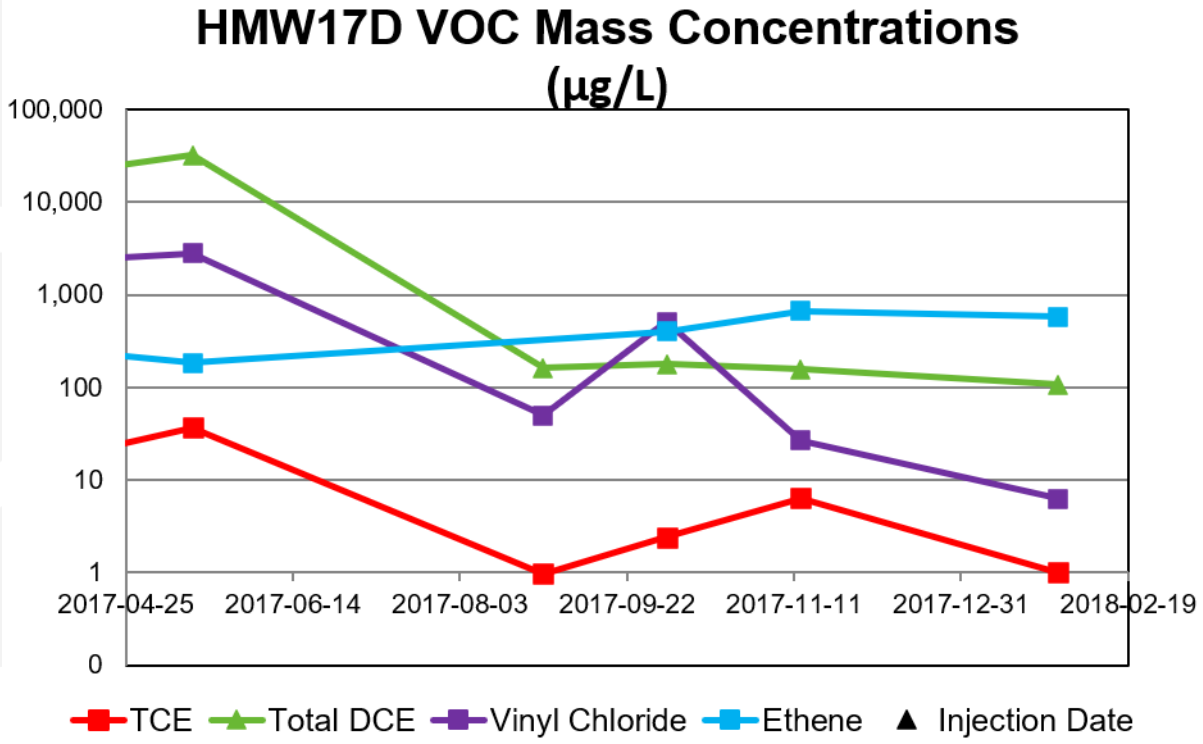
Emplacement confirmation

3D tiltmeter mapping

July 2017. Source: CDM Smith presentation, slides 15–18

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Bountiful: Groundwater Response



>99.5%

Source mass reduction, no rebound

~7 months between sampling events

Additional EVO did not proceed

HMW-17D. Source: 2018 presentation, slide 17 and embedded chart data

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Keystone Environemental, B.C: Pilot

The commercial property and adjacent land carried a high-risk classification that restricted the client's access to lending.

Objective: The owner intended to retain the existing use. The pilot tested whether injection could reduce the conditions driving that classification.

EHC-L: combined abiotic and biotic treatment

Organo-ferrous iron supports abiotic reduction.
Microemulsion supplies carbon for native microbes.
Carbon availability and iron cycling support persistence.
No additional Dehalococcoides culture.

2 injection boreholes

5.4–11.2 m bgs

Total Amendment

3700kg **EHC-L**
200kg **Potassium Bicarbonate**

January 2019

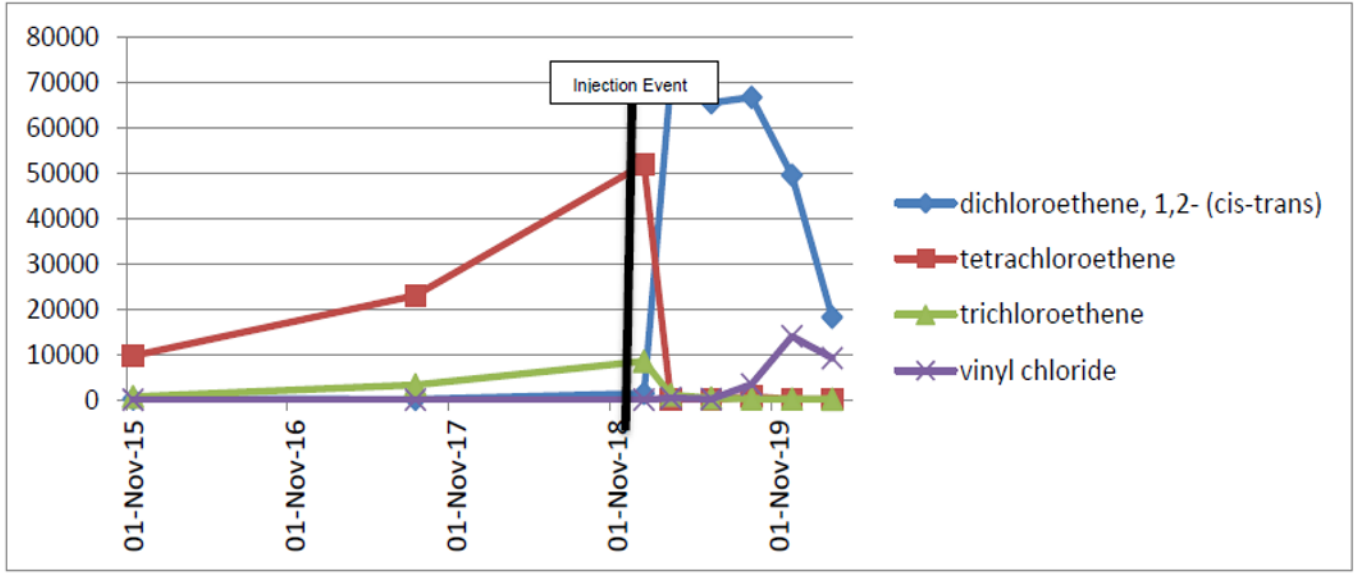
injection event

Keystone Environmental, March 2020 report and supplied client note

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Keystone, B.C: Groundwater Response

Figure 1 Monitoring Well MW15-3 Groundwater Concentration over Time



52,000 to 77 µg/L

Perchloroethene (PCE) January 2019 to March 2020

99.85%

PCE concentration reduction at this well

DCE remained at 18,230 µg/L in March 2020. Parent loss alone does not establish complete dechlorination.

MW15-3. Source: Keystone report, Figure 1, report p. 8

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Keystone B.C: High-Risk Conditions No Longer Identified

“It performed well enough that high risk conditions were no longer and therefore not a high-risk site.”

Client note

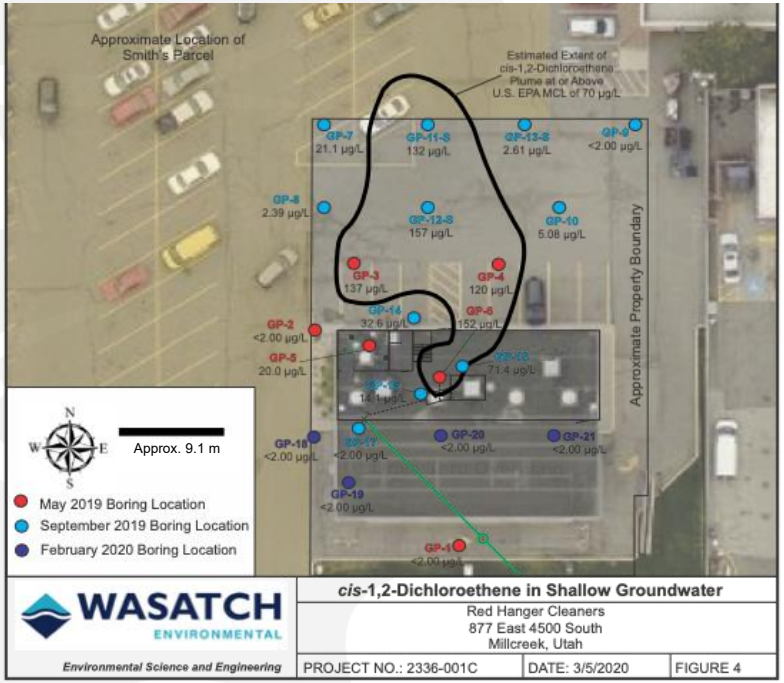
Reported endpoint

The March 2020 assessment concluded that high-risk conditions were no longer identified and requested an end to quarterly monitoring.

Residual conditions

Daughter products and off-site exceedances remained. Intermittent groundwater extraction also formed part of the site response.

Millcreek / Red Hanger: Site Background



Dry-cleaning site

Perchloroethene (PCE) use from 1987 to 2011. Groundwater impacts extended beneath the facility and to the north.

Treatment area

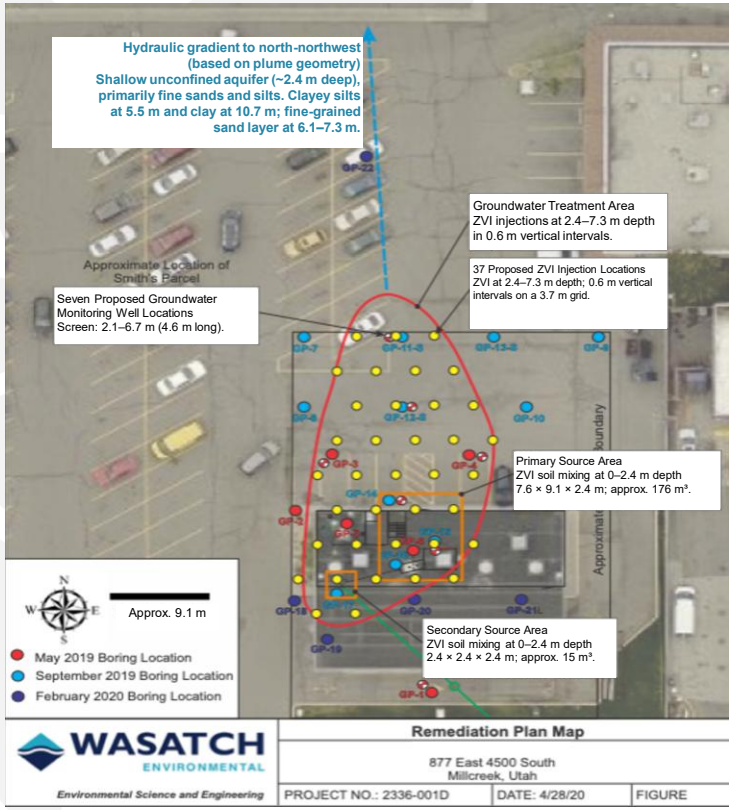
Approximately 430 m². Gravelly sand overlies sands and silts with lower hydraulic conductivity.

The selected remedy combined shallow source treatment and deeper groundwater treatment.

Client: Trillium. Consultant: Wasatch Environmental. Millcreek, Utah.

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Millcreek: ZVI Emplacement



Groundwater injection

~31.0 tonnes ZVI
27 boreholes
110 discrete intervals

2.4–7.3 m below ground
6 days of injection operations

Shallow source soil mixing

~3.95 tonnes ZVI
0–2.4 m below ground

Source: Battelle 2024 presentation, slides 8–11

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Millcreek: Groundwater Results

Compound	MW-3 result (µg/L)	MCL in source (µg/L)
PCE	<1.0	5
TCE	Non-detect	5
cis-1,2-DCE	23.4	70
trans-1,2-DCE	Non-detect	100
Vinyl chloride	Non-detect	2

All reported COCs below the listed MCLs

The source reports TCE, trans-DCE and VC as non-detect across sampling locations.

The source reports closure with a Corrective Action Plan with Controls.

March 2022. Source: Battelle 2024 presentation, slides 15–17

Treatment Decisions and Endpoints

Site	Observed response	Treatment decision / endpoint
Bountiful	Large decline at the source hot spot after ZVI and sand placement	Planned additional EVO not required Concentration response at HMW-17D
British Columbia	Strong parent-solvent decline High-risk conditions no longer identified	No additional culture added Client's risk objective addressed
Millcreek	March 2022 results below the MCLs listed in the source	Combined ZVI remedy met groundwater criteria

These cases support monitoring-led decisions on further treatment.

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Passive Treatment and Operating Demand

After emplacement

Reactive amendments remain in the target interval and can continue treatment between monitoring events.

Site management

Monitoring continues to track the response.

- Keystone also used intermittent groundwater extraction.
- Wasatch implemented soil mixing.

Field delivery

Often requires one emplacement. Does not require a long-term active approach.

Pumping Iron



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Total ZVI pumped

~690 tonnes

Know your site, contaminant and amendment.

Get a quality amendment to the right place.

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Conclusion

- **Site objectives define the treatment endpoint**
  - CDM Smith: Bountiful targeted and treated a source hot spot
  - Keystone Environmental Ltd.: Addressed high-risk conditions
  - Wasatch Environmental: Millcreek met reported groundwater criteria and allowed redevelopment
- **Amendment selection and delivery work together**
  - The Right Product and Place - targeting and contact influence the field response
- **Monitoring guides follow-on treatment**

Thank you

Clients

CDM Smith

Keystone Environmental
Knowledge-Driven Results

WASATCH ENVIRONMENTAL
Environmental Science and Engineering

Vendors

chemco

Supplied EHC-L

C.E.R.E.S.

Supplied ZVI

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