COMPARISON OF SOIL BLENDING, BULK REMOVAL WITH OXIDANT ADDITION, AND COMBINED REMEDIES FOR BROWNFIELD REMEDIATION

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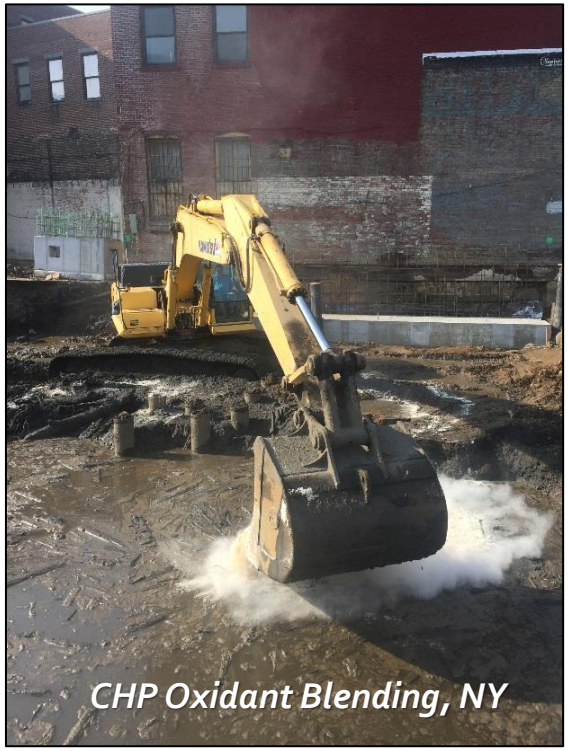
Overview

- Soil Blending Methods
- Chemical Treatment Technologies
- Case Studies



Soil Blending Methods

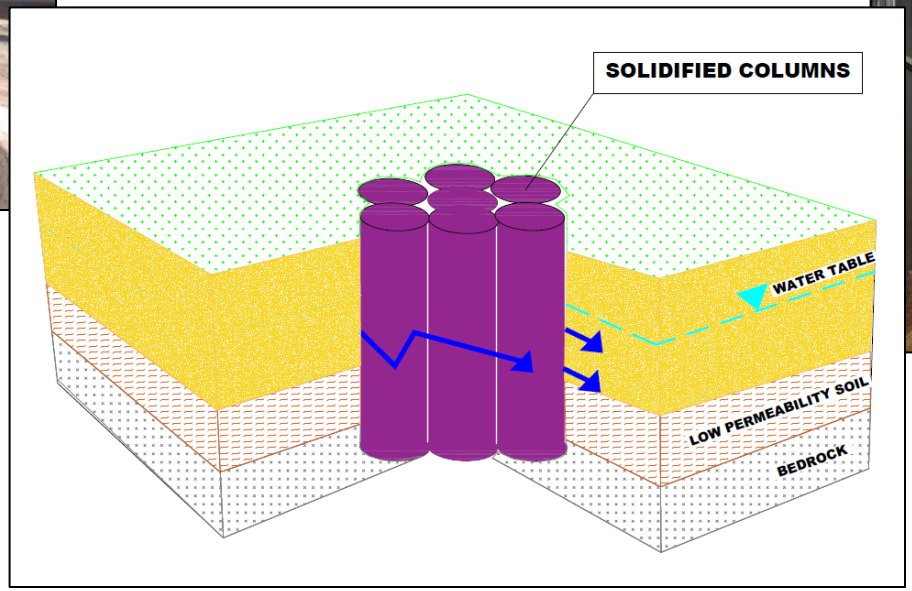
- Soil blending technologies were originally developed for deep soil stabilization for geotechnical purposes.
- These methods are adapted for remediation in the late 1980s/early 1990s using deep soil mixing rigs
- Soil mixing, as applied to remediation, refers to mixing chemical reagents (wet or dry) into contaminated soils and groundwater
- Soil blending can be performed in-situ (“in-place”) or ex-situ (“above ground”) using excavation equipment and auger or caisson drill rigs.

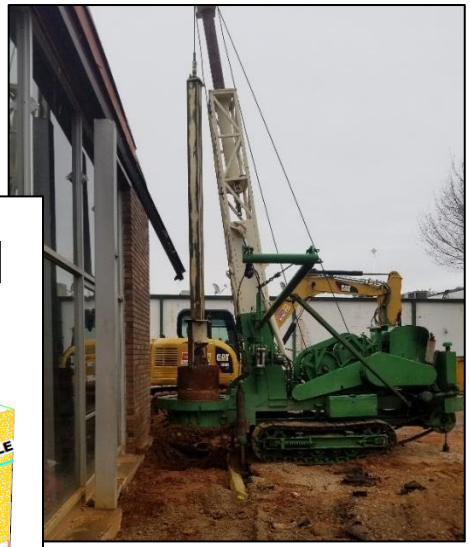
Soil Blending Methods: In-Situ

- In-Situ blending performed using excavators or augers
- Offers maximum contact
- Eliminates waste generation
- Treat soils AND groundwater together
- Allows treatment of low permeability soils
- “Green friendly” alternative to off-site land filling
- Cost effective alternative to In-Situ resistance heating

Soil Blending Methods: Modified In-Situ/Ex-Situ

- A low cost novel approach is soil blending utilizing a LDA bucket auger rig
- Soils are removed and segregated for ex-situ treatment in a roll-off using chemical oxidants, reductants, or bio-amendments
- Treated soils can be landfilled or amended with chemical additives and placed back in the LDA boring to allow long term treatment of groundwater



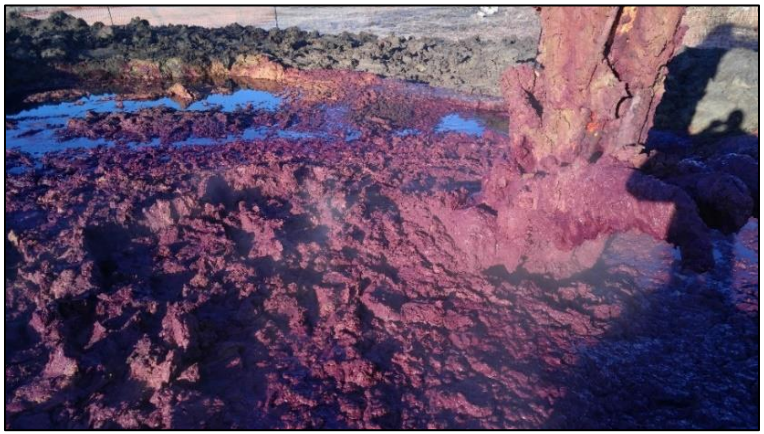


Soil Blending Methods: Ex-Situ

- Ex-situ blending involves removal prior to treatment
- Soils are typically screened and blended in a pug mill
- Soils can be stabilized after treatment for re-use
- Lower cost alternative to hazardous waste landfilling
- Can achieve lower treatment thresholds

Chemical Treatment Technologies

- **Chemical Oxidation (ISCO):** involves breaking bonds of organic molecules with insertion of oxygen and/or removal of hydrogen
- **Chemical Reduction (ISCR):** involves the addition of electrons (usually hydrogen ions) - mirror image of ISCO
- **Enhanced Bioremediation (ISB):** involves the addition of nutrients to stimulate aerobic/anaerobic microbial degradation (can be combined with ISCO/ISCR in a "treatment train" combined remedy)
- **Surfactants:** function like soap by reducing surface tension and solubilizing oil and nonpolar substances (*Not discussed further*).



Comparison of Oxidation vs. Reduction

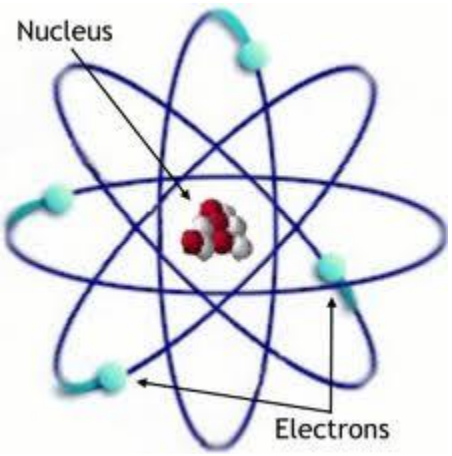
- Oxidation-reduction (redox) reactions involve electron transfer
- One half of the reaction shows an electron loss (oxidation)
- Opposite side of the reaction shows a net gain (reduction)

Oxidation of TCE using Sodium Permanganate

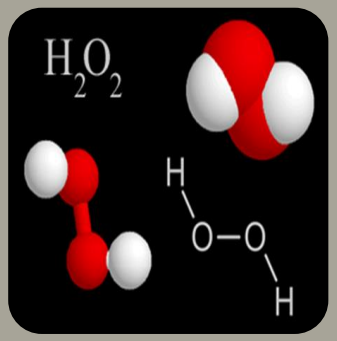
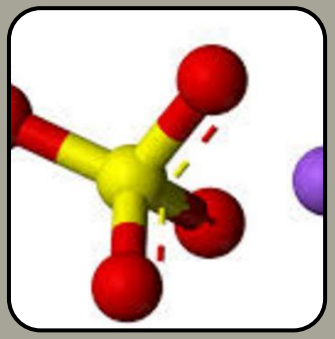
$$2NaMnO + C_2HCl_3 \longrightarrow 2CO_2 + 2MnO_2 + 3Cl^- + H^+ + 2Na^+$$

Reduction of TCE using Zero-Valent Iron

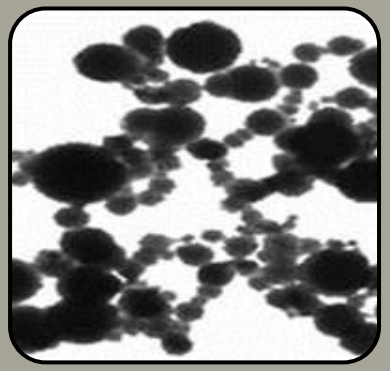
$$3Fe^0 + 3H^+ + C_2HCl_3 \longrightarrow 3Fe^{+2} + 3Cl^- + C_2H_4$$



Common Oxidants/Comparisons

Fenton's Reagent	Catalyzed Hydrogen Peroxide	Peroxygens Modified Fenton's	Sodium Persulfate	Permanganate
				
Hydroxyl radicals have high oxidation potential (2.6-2.8 eV) Can treat wide variety of organic compounds Fast reaction Ideally suited for soil blending Rapid desorption Difficult to inject May require pH adjustment	Chelators slow decomposition and hydroxyl radical formation Limited radial influence- requires larger injection volumes Very useful for soil matrix desorption/ NAPL destruction Per pound least expensive oxidant	Offers unique combination of ISCO (H_2O_2) + aerobic bioremediation No residual salt by-products Slurry- low solubility Limited ROI Higher Cost may require combining with other oxidants	Versatile, easy to inject Sulfate radicals comparable in oxidant strength to $OH^{\cdot -}$ pH activation can be difficult to maintain Consider utilizing naturally occurring iron when feasible	Selective oxidant No radical chemistry Excellent subsurface longevity Useful in PRBs or slow release applications May utilize in tandem with other oxidants Treatability study recommended

Chemical Reductants & Comparisons



Calcium polysulfide and sodium dithionate: useful for metal reduction (hexavalent Cr), relatively inexpensive

(high DO, low pH, lack of iron affects cost)

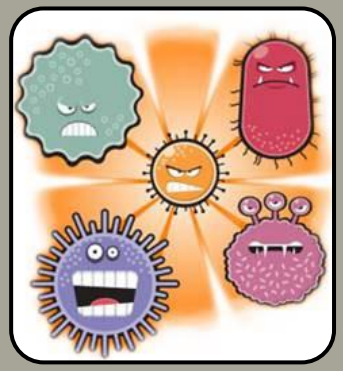
Produces iron sulfides

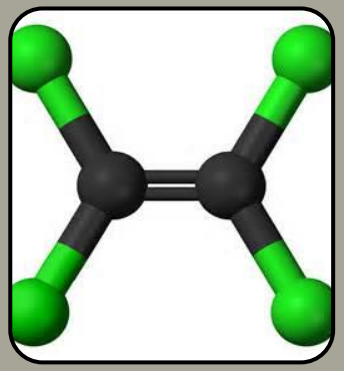
ZVI/Zero valent metals: treats chlorinated VOCs, select SVOCs, various metals, requires injection under high pressure, limited ROI, commonly used in PRB, rapid iron oxidation may limit permeability

nZVI: provides more subsurface mobility and reaction surfaces, polyphenol generated nZVI can be produced in-situ via liquid reagent injection, greater ROI & versatility

Iron Sulfide: used for chlorinated VOCs and select metals, can create reaction using liquid injection or solid phase reactants in a PRB, similar reaction to ZVI

Enhanced Bioremediation (ISB)





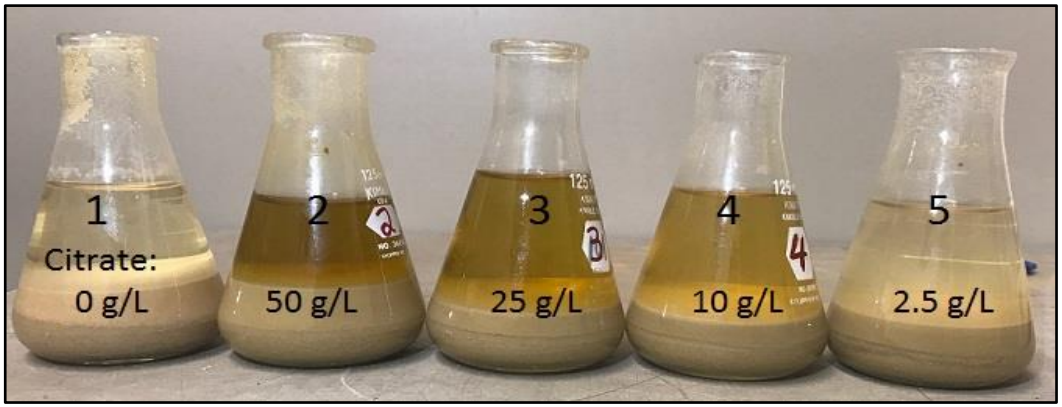
ISB involves the injection or addition of nutrients to stimulate microbial degradation	Petroleum hydro-carbons including aromatics and straight chain compounds commonly reduced aerobically	"Treatment Train": ISCO + aerobic bio-stimulation. Useful in blending scenarios paired with oxidants or reductants.	Sulfate reducing bacteria - petroleum fuels or add iron for treatment of chlorinated VOCs	Chlorinated VOCs treated anaerobically reductive de-chlorination (lactate, soybean oils, etc.)

Treatability Studies

- Determines most effective chemical amendments and dose
- Crucial for dose determination in soil blending!
- Slurry reactors created using soil/GW from "hottest" zone
- Studies typically require 4-6 weeks and include third party laboratory analysis
- Preliminary treatment designs/conceptual designs provided with each study
- Costs range based on number of reactors, usually between **$8K-12K**

Batch Reactor Set-up

Permanganate Batch Reactors

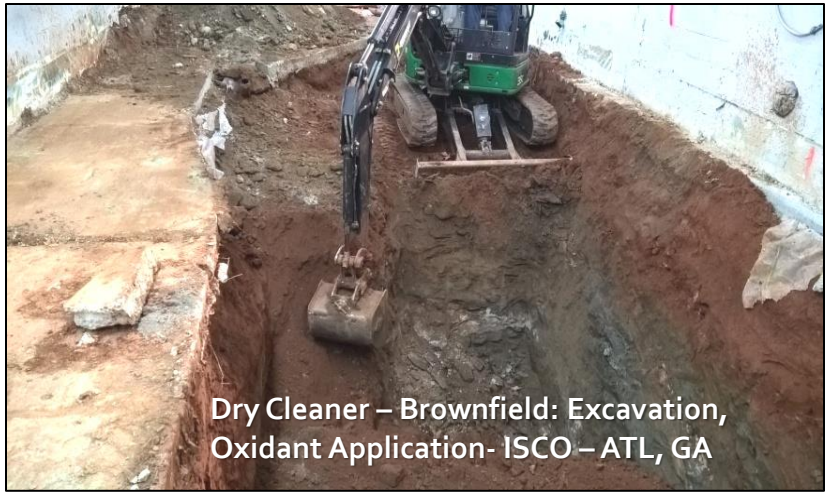


Iron Leachate Testing

Column Testing

Select Case Studies

1. Soil Blending, Industrial VOC Treatment – West Point, MS
2. Ex-situ Soil Blending, Lead Treatment – AL Shooting Range
3. Soil Excavation/Dry Oxidant Application – Charleston, SC
4. LDA Solid Phase Oxidant Treatment – Gainesville, GA
5. Ex-situ Blending-ISS-ISCO-Dry Cleaner/Brownfield – Atlanta, GA
6. Ex-situ Soil Blending, Petroleum VOCs/PAHs – Yonkers, NY
7. Active Wood Treater – Manor, GA (*On-going*)
8. Tank Farm/RCRA/Brownfield Site – Opelika, AL

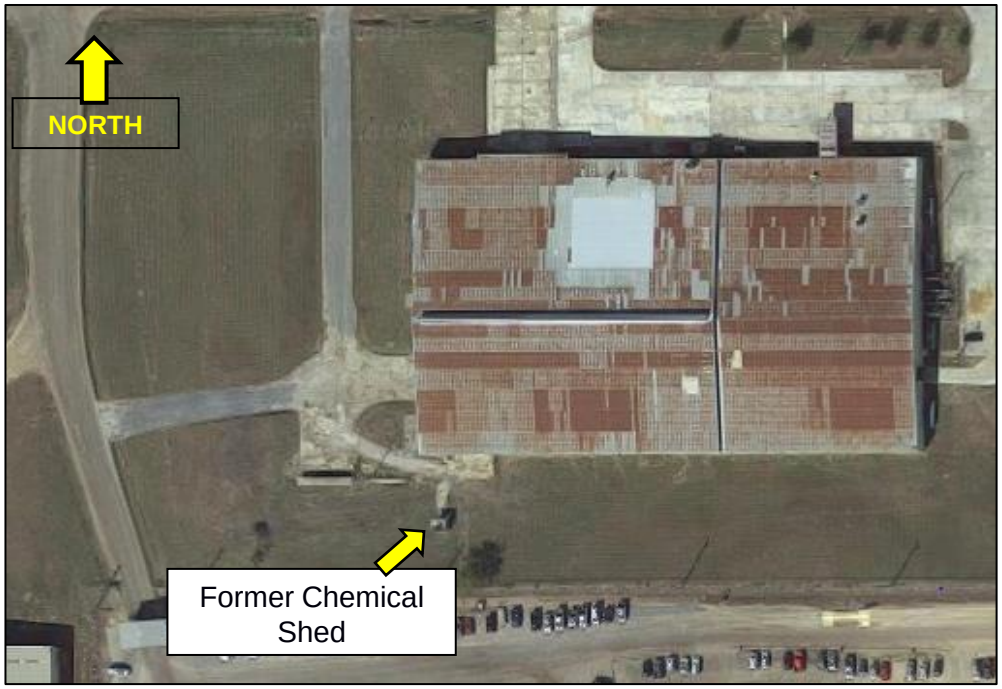

Dry Cleaner – Brownfield: Excavation, Oxidant Application- ISCO – ATL, GA


ISCO - Bronx, NYC

In-Situ Soil Blending - West Point, MS

Overview

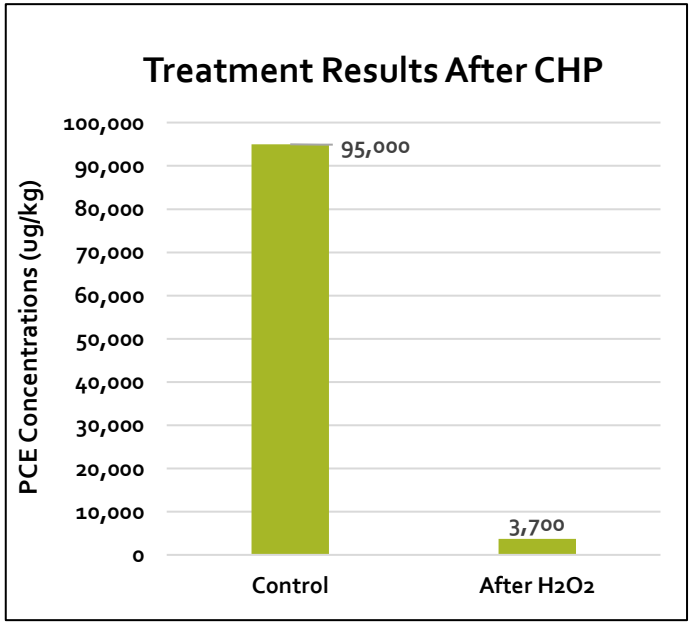
- Inactive industrial facility with elevated levels of PCE, TCE, cis-1,2-DCE, xylenes, and ethylbenzene in soil/GW under a storage shed.
- Highest total VOCs – 23,410 ppb.
- Limited plume size (3,500 SF) due to low permeability clayey-silts which also perched the WT (5'-15').
- Analytical data suggested past abiotic or reductive de-chlorination with a typical cis-1,2 DCE stall.
- Eden recommended in-situ oxidant soil blending in the former shed location (525 SF) and ISCO injection in the remaining plume.



ISCO/Soil Blending - West Point, MS

Treatability Study

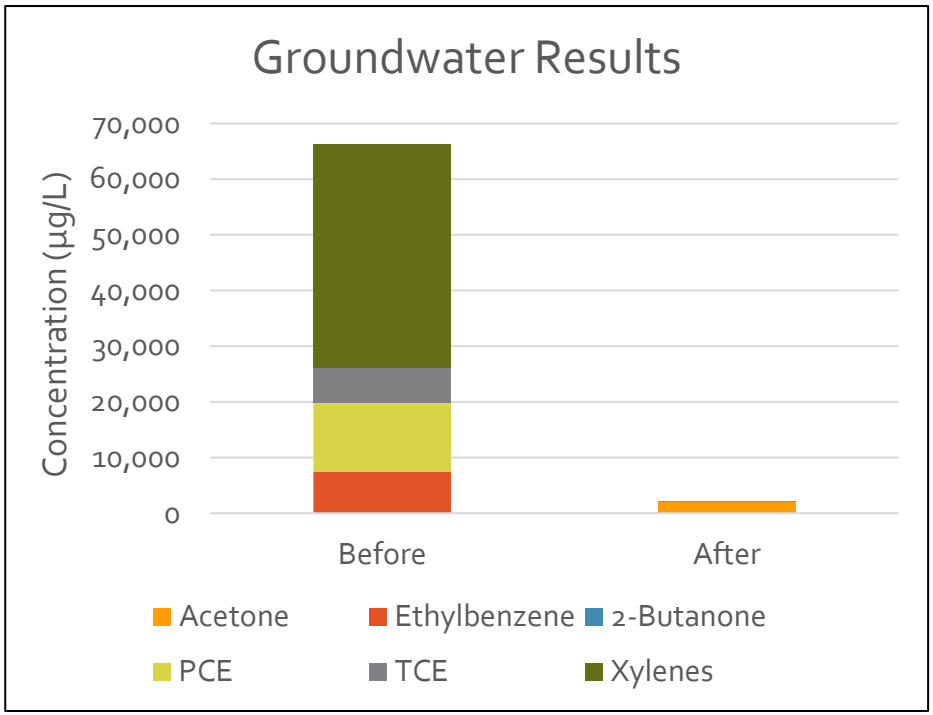
- Treatability study performed to select the best oxidant and dose for blending.
- Study compared CHP/MF with/without iron, alkaline activated SPS, and KPM.
- Findings indicated CHP with iron salt and KPM best suited to site conditions.
- Treatment scope developed by Eden included blending using approximately 21,900 lbs of HP + iron salt (MF) followed by addition of 22,000 lbs of potassium permanganate.

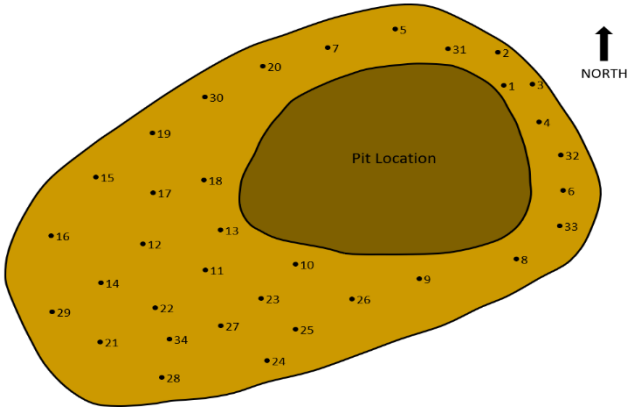


Soil Blending - West Point, MS

Results

- Preliminary results indicate MF alone oxidized PCE by approximately 97%.
- Following completion of blending, ISCO injection was performed using 34 DPT pts applying 2,500 lbs of potassium permanganate into the remainder of the plume.
- Confirmatory soil and GW sampling performed in July 2018 indicated trace to low level VOCs conc below target levels!
- NFA letter received in September 2020 from Miss Brownfield Voluntary Clean-up Group.
- Total Cost < $165,000





Ex-Situ Blending – Shooting Range, AL

Overview

- Site is a former shooting range and historic “dump”.
- Earthen berm contained lead contamination from spent cartridges, approx. 100 cubic yards failed TCLP (total lead >1,000 ppm).
- Eden conducted a treatability study to identify best fit chemistry for reduction/ stabilization.
- Treatability study compared various blends of lime, Portland cement, metakaolin, silica fume, and calcium polysulfide.
- Optimal treatment conditions created using a 5% calcium polysulfide solution followed by 7% Portland cement powder.

Ex-Situ Blending – Shooting Range, AL

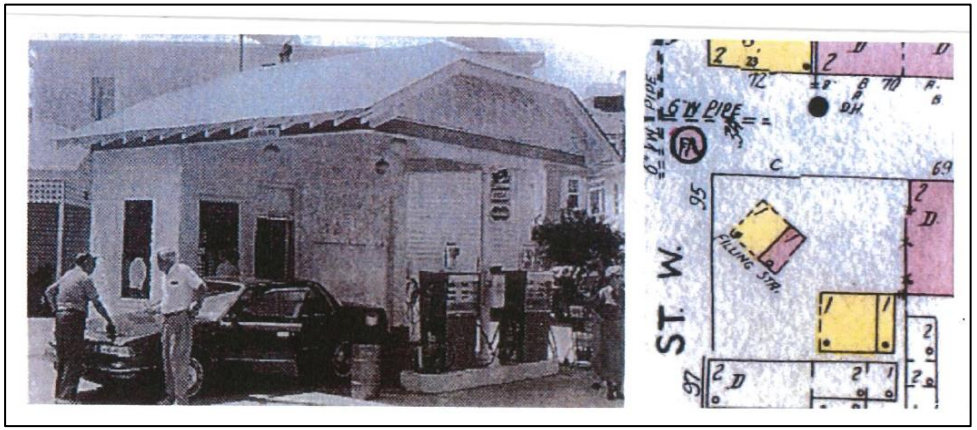
Treatment Summary

- Scope included excavation and power screening using a trommel screener to remove rocks/debris (>1/2”).
- Soils targeted for blending (approx. 100 cubic yards) were directed into lined roll-offs.
- Remainder of the soils were transported to a Subtitle D landfill.
- Soil blending was performed using a spray application of calcium polysulfide followed Portland cement.
- After approx. 24 hours of partial curing, TCLP lead samples were collected. All TCLPs were ND which allowed Subtitle D landfill disposal.

Soil Excavation/Dry Oxidant Application Charleston, SC (State Lead Site)

Overview

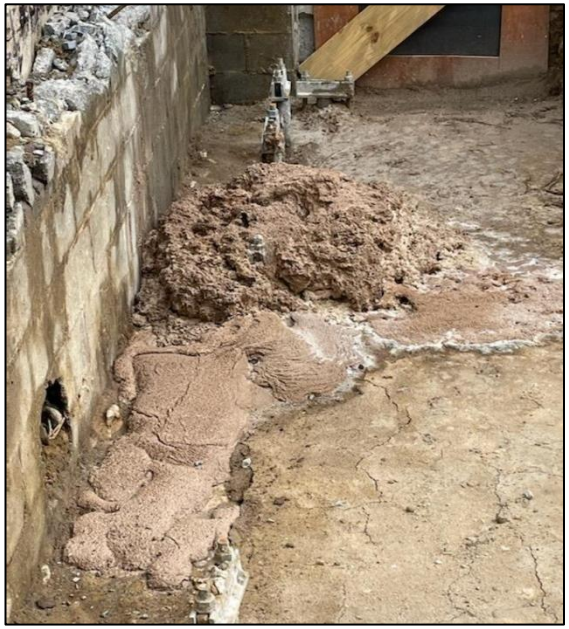
- The site was a historic gas station constructed in the 1930s in the historic district of Charleston. The gas station structure was demolished and later replaced with a private residence in 2000-2001.
- A shallow water table at 3'-7' was present with up to a foot of a waste oil product detected in one well adjacent to the rear patio. BTEX impacted soils from an apparent gasoline fuel source were also detected under the rear patio and a portion of the crawl space. Past remedial efforts were limited to mobile vacuum extraction events.
- The scope of work included soil removal under the patio and crawl space followed by installation of a gravel-oxidant treatment barrier and construction of a vapor barrier.



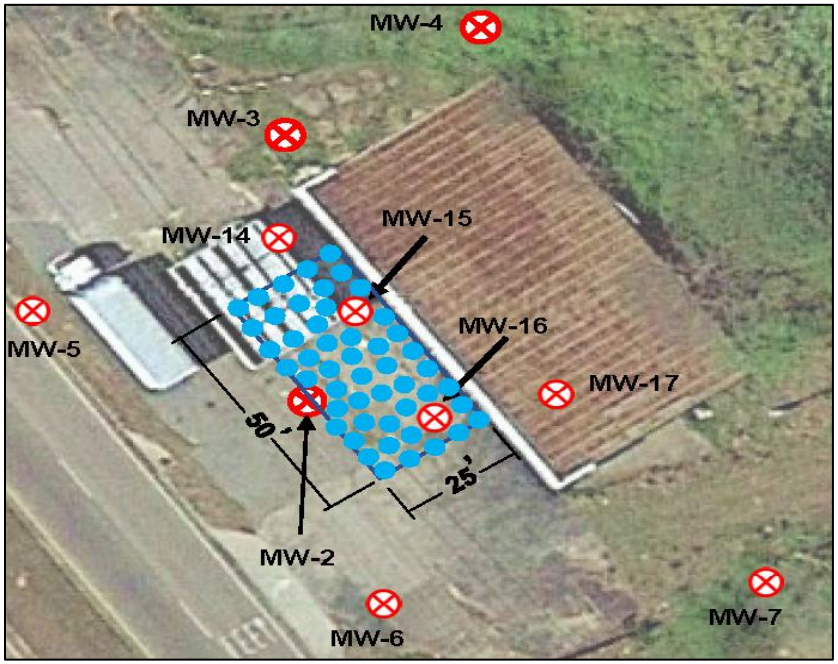
Soil Excavation/ISCO "Wetting Bed" Construction Charleston, SC (State Lead Site)

Treatment Summary

- Prior to excavation, helical foundation supports were installed to depths of 50-60 feet in the Cooper Marl clay at a specific torque ratio.
- After securing the foundation, petroleum impacted soil (<100 tons) was excavated followed by the application of approximately 20,000 lbs of un-activated sodium persulfate at 6-8 feet. Due to limited access, some excavation was performed manually.
- Limited surfacing of reacted sodium persulfate was initially observed in one or more areas. Backfill compaction followed engineered specifications
- The site was closed in December 2021 after site restoration.



LDA Solid Phase Oxidant Treatment – Gainesville, GA



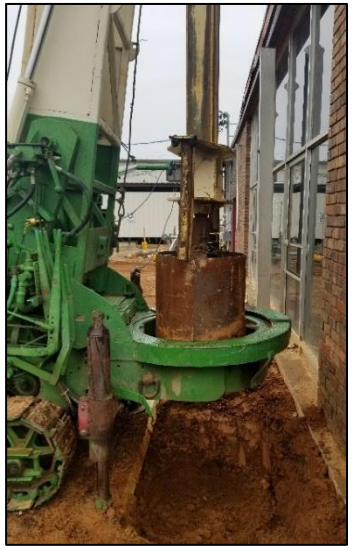
- Former convenience store with gasoline fuel contamination. Traces of free product with dissolved benzene >20,000 ppb.
- Prior remedial attempts following tank removal included mobile vacuum extraction, pump-and treat, limited ISCO, and gravity feed In-situ bioremediation (ISB). ISCO and gravity feed ISB failed due to poor compaction in the tank pit.
- Eden proposed treatment using approx. a series of closely spaced LDA bucket auger borings advanced to 28 feet on 5 foot centers. The bucket augers were 2.5'-3' in diameter.

- In October-November 2019, 160 tons of impacted soils were removed and landfilled from 12-28 feet and the void space was backfilled with gravel and a combination of calcium peroxide, sodium percarbonate (3-5% oxidant dose) with chelators.
- Follow-up sampling confirmed free product removal and a satisfactory reduction in dissolved benzene/BTEX. A NFA was granted in February 2020
- Total cost was <$175,000.

Excavation-Ex-situ Oxidation/Dry Oxidant Bed/ISCO Dry Cleaning Facility/Brownfield-Atlanta, GA - ***Overview***

- Site is a former dry cleaner with extensive fill to depths of 12'-17'. GW depth is 20-25'. PCE mixed with non-halogenated VOCs present from a possible drain or drum storage release
- The treatment area was 2,155 SF with a vertical profile of 5'-17'. Due to the high concentrations of PCE in soil (>20,000 ppb) and the owners desire to save the building, the treatment strategy included excavation and ex-situ oxidant blending of impacted soils, LDA soil removal next to the foundation, and ISCO inside building.
- Treatability findings identified MF with metakaolin stabilizers for ex-situ blending/stabilization, and KPM for injection and for a wetting bed constructed in the base of excavation.

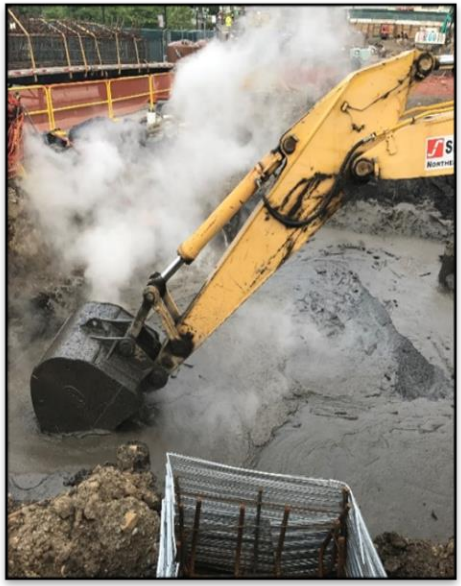
Dry Cleaning Facility/Brownfield-Atlanta, GA – ***Treatment Summary***



- A total of 970 tons of impacted soils were excavated and 200 tons were pre-treated in roll-offs ex-situ using MF for VOC oxidation. After treatment, soils were hardened and stabilized using metakaolin prior to TCLP analysis and off-site Subtitle D landfilling.
- Injection was performed inside the building at 8'-16' using a 2-3% solution of potassium permanganate. Injection was performed on a tight grid spacing with a 2-3 foot spacing. Approximately 150 injection points were utilized.
- Confirmatory soil samples collected inside building and on the base and sidewalls indicated target treatment goals were met or exceeded. A KPM-gravel "wetting bed" was installed at the base of the excavation for long term GW treatment.
- A series of 10-15 side-by-side bucket auger borings were advanced to remove and treat remaining impacted soil adjacent to foundation. KPM-gravel wetting beds were created in the bottom 1-2' of the borings.
- Follow-up GW sampling indicated concentrations <Commercial RRS.
- Georgia EPD provided the final LOL letter in January 2020

Ex-Situ Soil Blending – Yonkers, NY

- Eden performed a “rush” ex-situ soil blending treatment for a redevelopment in the City center. Contaminants included petroleum aromatics, PAHs and LNAPL from multiple abandoned USTs.
- Treatment was performed in an open excavation (LNAPL and impacted soils and GW).
- Shallow water table with tidal influence from the Hudson River.
- Fenton’s/Modified Fenton’s oxidation used for LNAPL removal and soil matrix desorption followed by un-activated SPS.
- Treated 1,420 tons using 1-2% oxidant by mass, areas were “spray” applied and blended with an excavator.
- Recent finding indicated treatment goals were met and/or exceeded!!
- Cost was <$150,000.

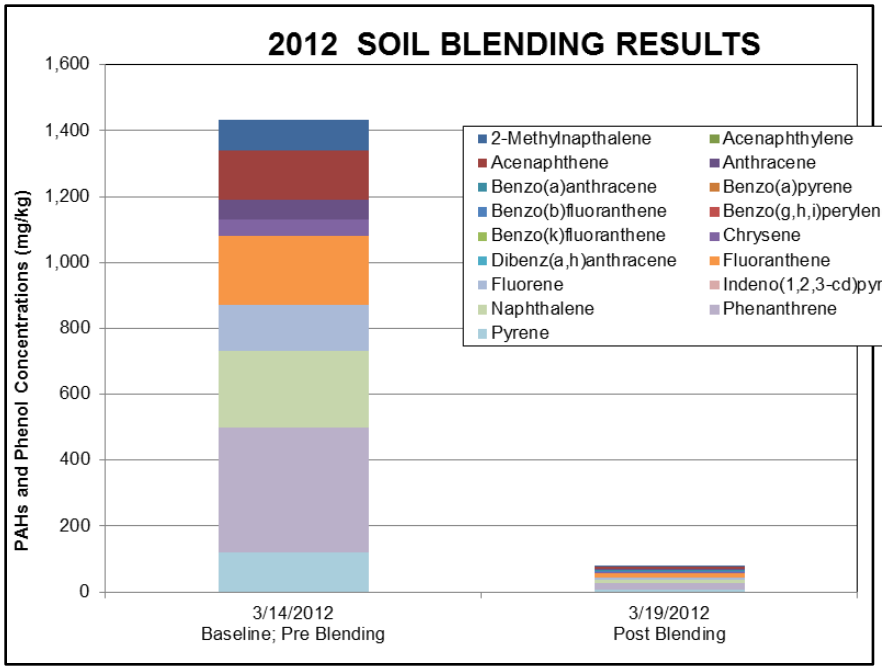


Soil Blending - Wood Treatment Facility- Manor, GA

- Site in Coastal Plain Province near Okefenokee Swamp.
- Creosote and penta-chlorophenol (PCP) impact in surface impoundment.
- NAPL present with dissolved PAHs to 45-55’.
- Proposed corrective action includes ISCO/soil blending.
- Down-gradient permanganate “candle” PRB proposed.

Soil Blending - Wood Treatment Facility- Manor, GA

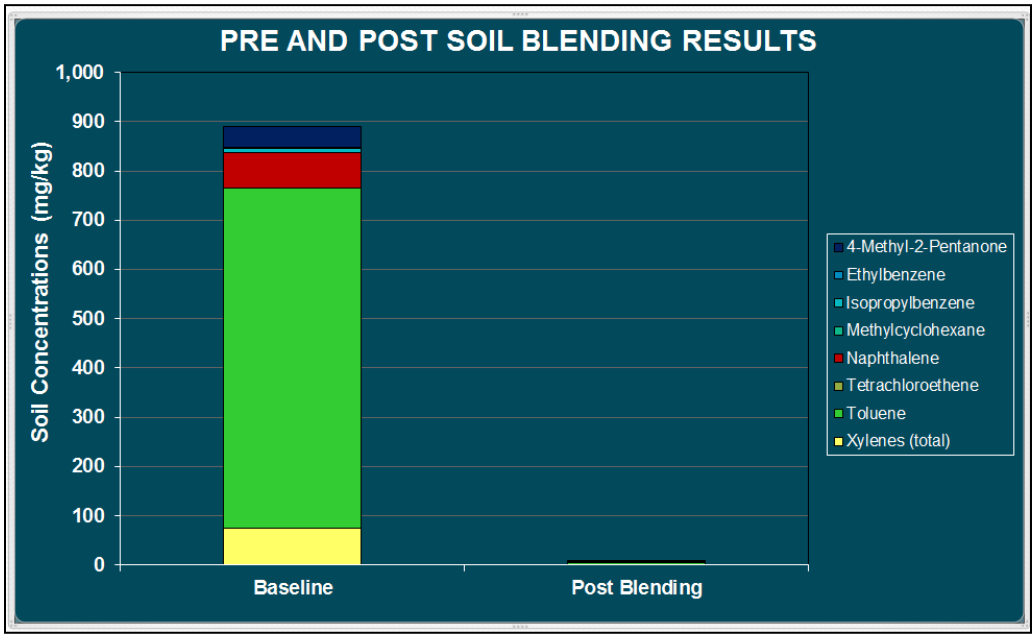
- An initial soil blending pilot resulted in NAPL removal from CHP-permanganate oxidation.
- Follow-up pilot used high volume dose of CHP only with significant reduction observed < target goals.
- Full scale treatment pending



RCRA/Brownfield Site- Opelika, AL

Soil Blending Case Study

- SWMU assessment identified LNAPL trace and VOCs (naphthalene and toluene) in former paint solvent tank farm.
- Highest total VOCs: 1,000-5,000 ppm.
- ADEM required haz disposal, in-situ blending offered as an alternative.
- Treatment performed using CHP+SPS on 300 tons of soil from 2-10’.
- Confirmatory sampling indicated VOC reduction to below risk target levels.



Eden Remediation

Services We Offer

- Soil Blending (In-Situ/Ex-Situ/LDA modifed auger blending approaches)
- Chemical/Enhanced Bio Injections (ISCO/ISCR/ISB)
- Surfactant Applications
- Source Area Treatments (including sites with active remediation systems)
- Full-service Envir. & Geotech Drilling including direct push probing, auger drilling, air/mud rotary, and rock coring
- Rapid Closure Strategies
- Treatability Evaluations
- Services offered nation-wide/HUBZone certified