Optimized Cleanup Outcomes Through Proactive Combined Remediation

ISOTEC

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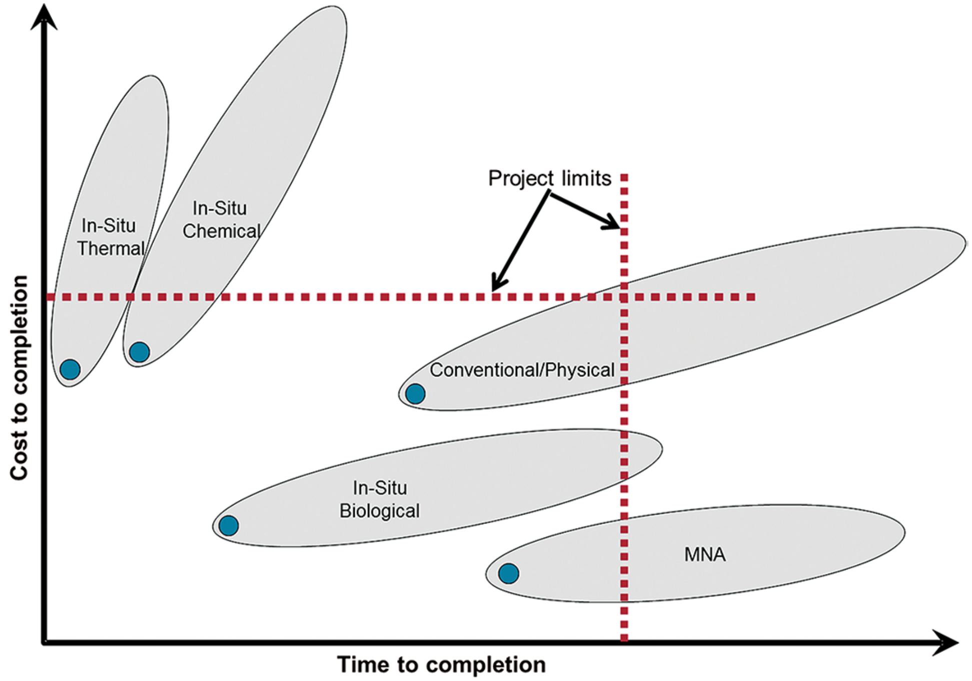
Remediation Timeline and Cost

- Time to meet goals inversely proportional to cost
- Feasibility Studies underestimate remediation time and cost
- Feasibility Studies/Decision Documents often select one remediation technology



- Nominal estimate of time and cost developed during the feasibility and design phases

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Combined Remediation Tools

- One tool cannot be used in all situations

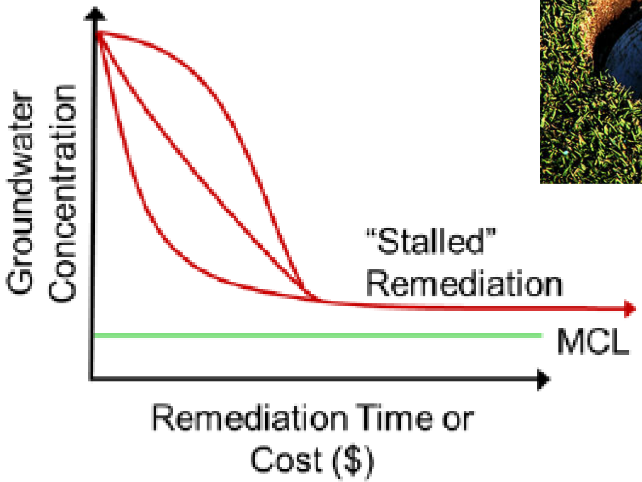
- Utilize multiple processes
  - Different contaminants, phases, concentrations and/or different site ‘compartments’
  - Identify synergies

- “How You Do It Is As Important as What You Do”
  - Flexible, Adaptive, Attentive

    -Jim Cummings, USEPA

Reactive Combined Remedies

- "Now What?" Combined Remedy
  - First approach did not fully meet goals
  - Change in conditions
  - Technology limitations



Tyler Marcet, PhD Dissertation, 2018

- Still closer to the hole than when the project started
  - Know when to change approach

Reactive Combined Remediation

- Active Site with Shallow GW (<1-6.5 ft bgs) – mixed VOCs
- Phase 1 – 2 ISCO injections (not by ISOTEC)
  - Catalyzed Hydrogen Peroxide (low pH)
  - VOC reduction, BUT day-lighting & asphalt mounding
- Phase 2 – 3 ISCO injections (ISOTEC)
  - Fe-EDTA Activated Sodium Persulfate
  - VOC reduction, BUT soil oxidant demand 4x larger than estimated
- Phase 3 – ERD for CVOCs (ISOTEC)
  - EVO with DHC Bioaugmentation
- Phase 4 – PRB at downgradient boundary (BOS 100® - ISOTEC)

Proactive Combined Remediation

"While we are seeing more proactive uses, the majority still seem to be reacting to limitations of the single selected remedy. Usually, those limitations should have been acknowledged upfront and a complementary technology should have been added."

-Ed Gilbert, EPA Technology Assessment Branch Chief

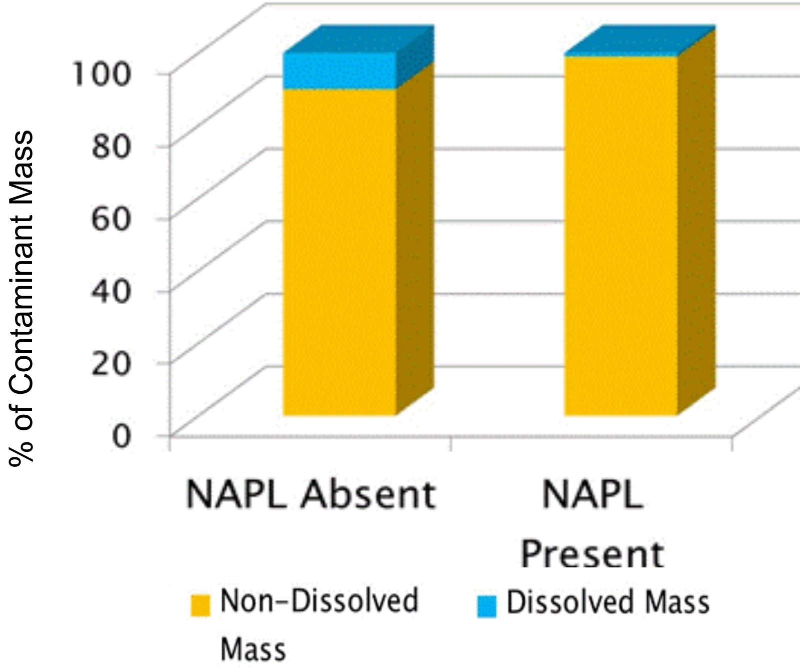
- Plan includes different technologies
  - Harness advantages of all technologies
  - Engineered Sequencing
  - Inclusion in Work Plan/Decision Documents

Remediation Byproducts

Technology	Reaction Product	Benefit	Inhibition
ISCO – H_2O_2	Oxygen	• Oxygen for aerobic biodegradation	• Terminal electron accepter (ERD) • Oxidizing Conditions
ISCO – MnO_4^-	Manganese		• Terminal electron acceptor demand • H_2O_2 catalyst • Oxidizing Conditions
ISCO – $Na_2S_2O_8$	Sulfate / Sulfuric Acid	• Sulfate Reducing Bacteria • FeS / abiotic dechlorination	• Terminal electron acceptor demand • Low pH • Oxidizing Conditions
ERD	Carbon Substrate	• Contaminants more available for treatment	• Oxidant Demand
Surfactant		• Contaminants more available for treatment	• Oxidant demand

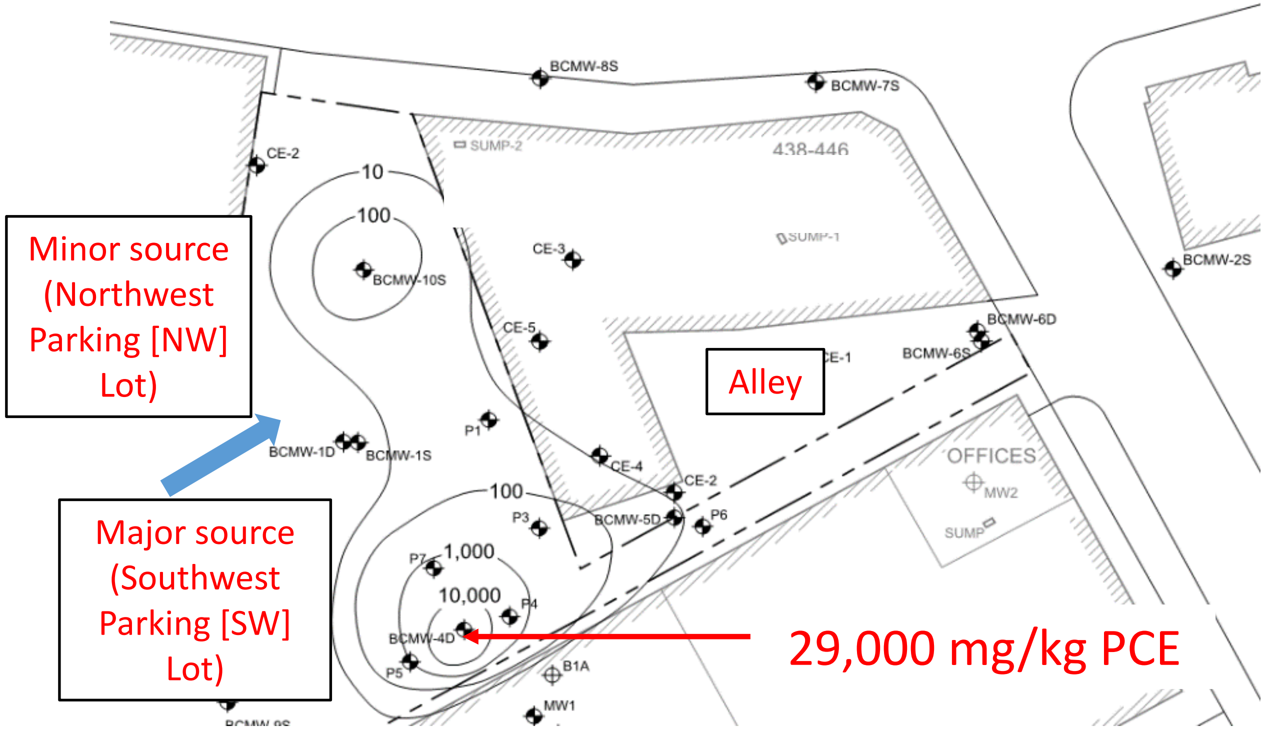
Combining Remediation Technologies

- Many in-situ remediation technologies react directly with Aqueous Phase contamination
- Most contaminant mass Not in Aqueous Phase
  - Sorbed to Soil
  - NAPL
- Design remediation to reduce mass of non-aqueous contamination



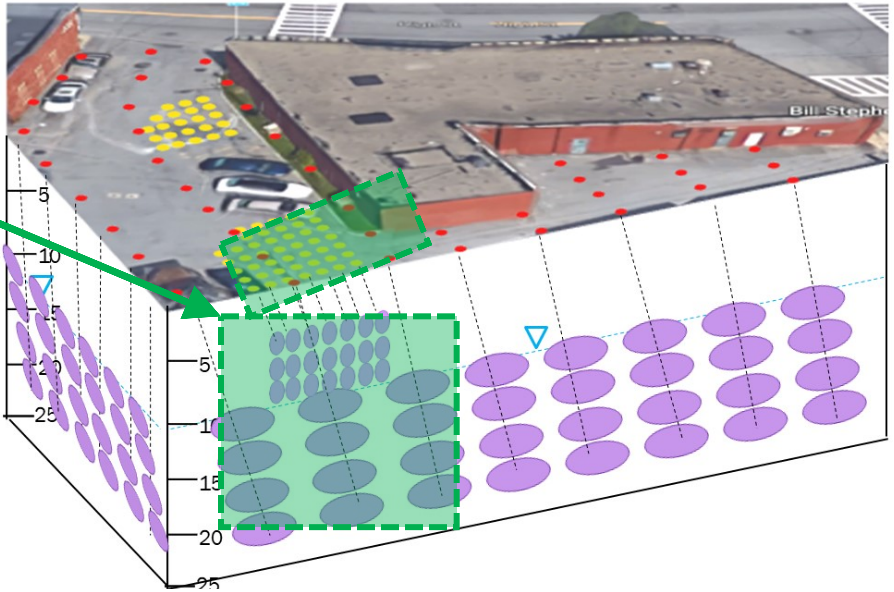
Surfactant + ISCO at Brownfield Site

- EPA Brownfield Cleanup Grant
- Municipal Parking Lot
- Highest PCE soil concentration in vadose zone
- Correlation between highest PCE in soil & highest GW and soil gas concentrations
  - NAPL?



Surfactant + ISCO at Brownfield Site

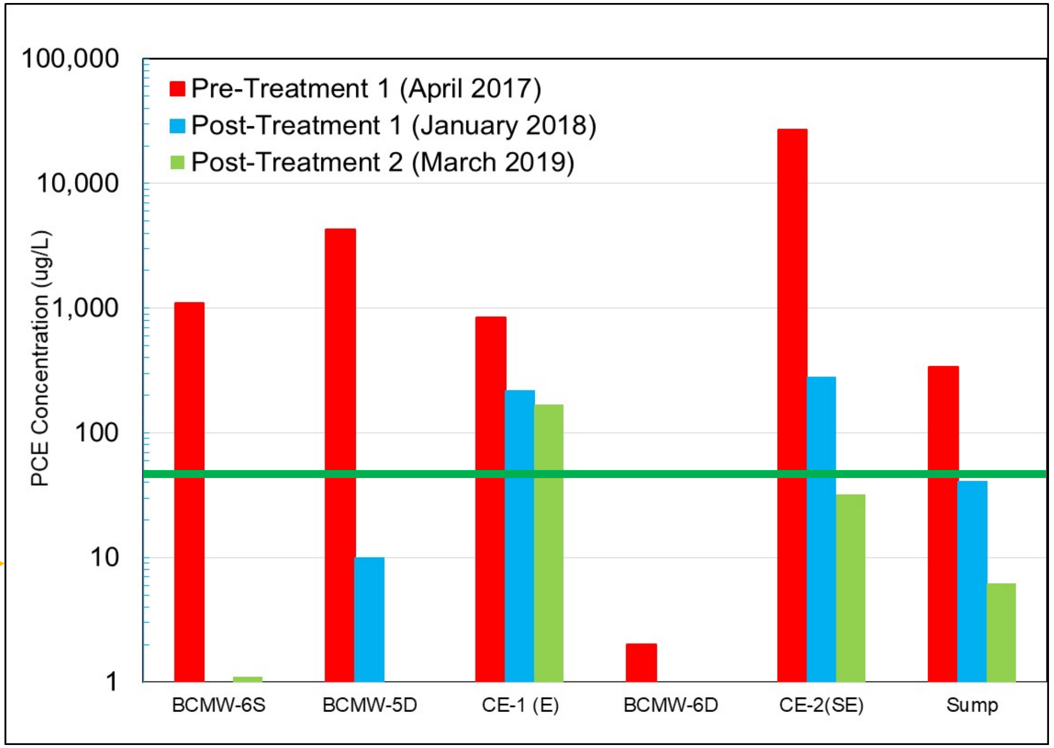
- 40 injection points for saturated soil (9-23')
  - Red points
- 65 injection points for unsaturated soil (3-9')
  - 5' grid
  - Yellow points
- Injection Sequence
  - ISCO downgradient before surfactant
- Follow-up injection with focused scope



S-ISCO License Agreement between ISOTEC & EthicalChem

Surfactant + Permanganate Results

- PCE below GW criteria (50 μg/L) in 13 of 17 wells 11 months after 1st injection
- After 2 injections
  - Well CE-2: 27,000 to 280 to 32 μg/L



Multiple Oxidant Remediation

Oxidant	Benefit	Limitation
Activated Sodium Persulfate (ASP)	• **Persistent oxidant (weeks to months)** • Effective for broad range of COCs	• **Effective for aqueous phase contaminants**
Catalyzed Hydrogen Peroxide (Modified Fenton's Reagent, MFR)	• Rapid oxidation • **Encourages desorption** • Effective for recalcitrant compounds • Activator for persulfate	• **Short persistence (hours)** • Increase groundwater concentrations from desorption

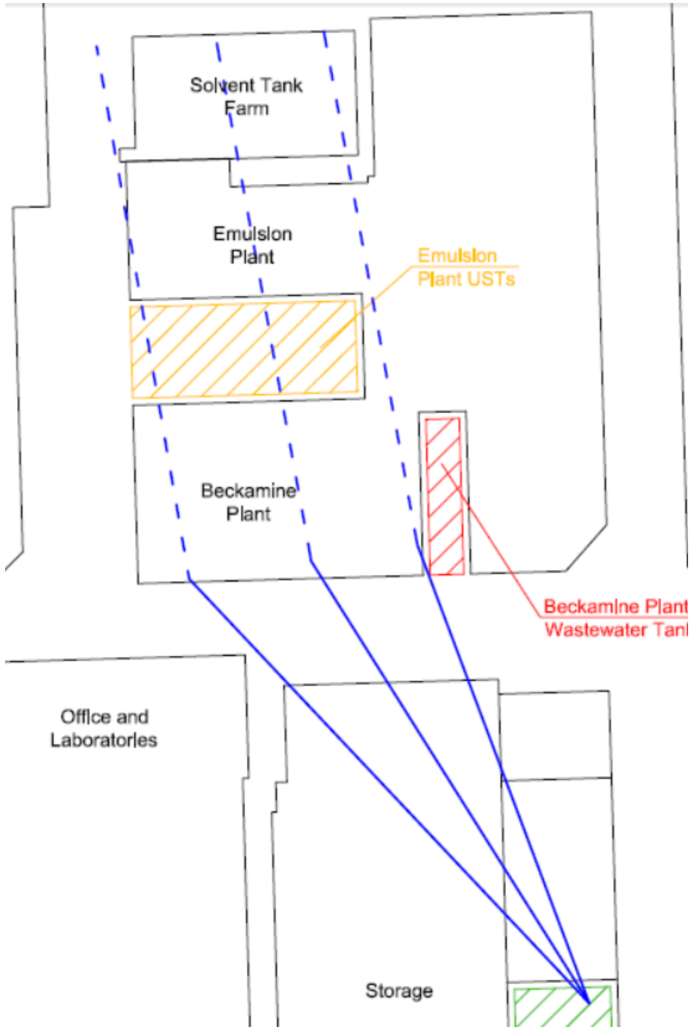
- Enhanced ISCO for CVOCs, petroleum, PCP, MGP, 1,4-dioxane
- Sequencing can be MFR-ASP or ASP-MFR or MFR Activator for ASP

Combined Oxidant Case Study

- Downgradient of Former MGP
  - VOCs & PAHs
  - Free-phase NAPL, blebs, and stringers
- Geology: Primarily clay
  - Sand and gravel lenses where blebs observed
- Bench Scale Tests
  - Sequences of MFR & Base Activated Sodium Persulfate
- Injections
  - Round 1: Low Dose H2O2 → Higher Dose H2O2 → BASP
  - Round 2&3: BASP → Low Dose H_2O_2 → Higher Dose H_2O_2 → BASP

Combining Chemical Oxidation & Bioremediation

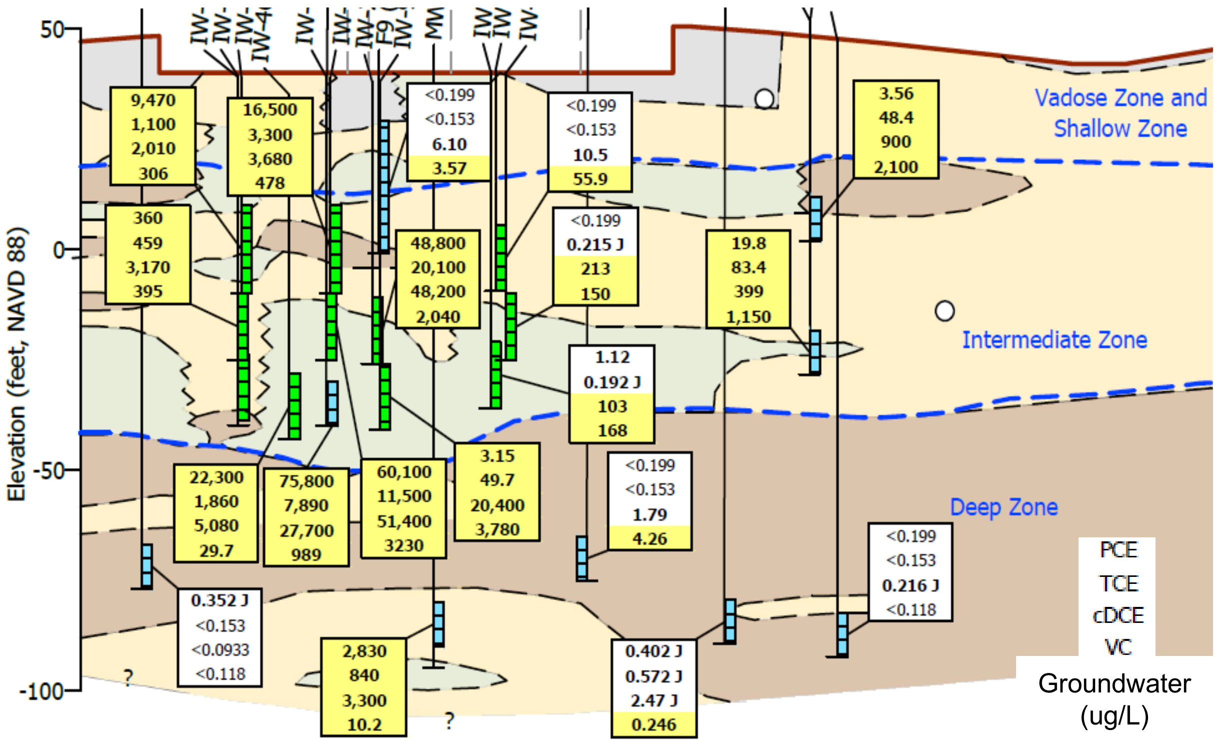
- BTEX impacts from historic USTs and solvent tank
  - Impacts under buildings
- Combined Remedy with 3 horizontal injection wells
  - ISCO with MFR (cost, desorption, oxygen byproduct)
  - Biosparging



Former Industrial Laundry

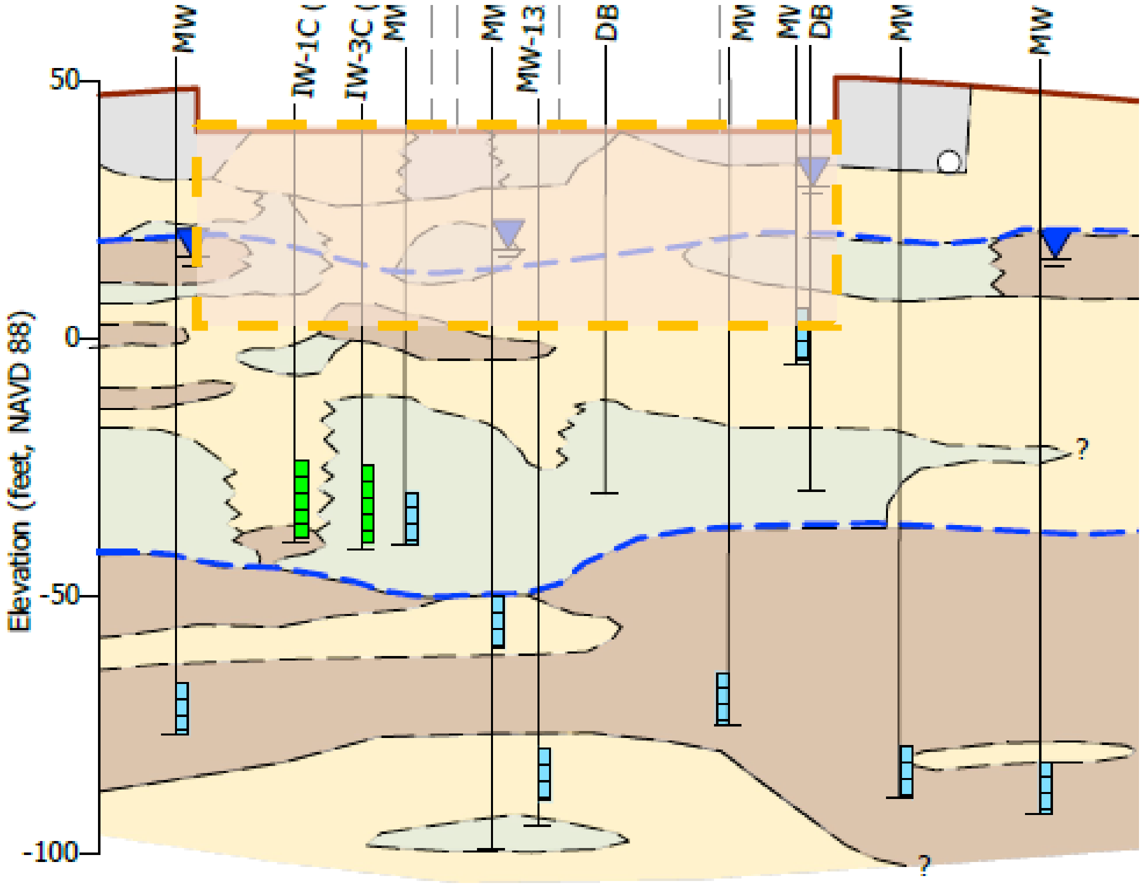
- Maximum PCE 237 mg/kg
- Depth to groundwater ~ 25’ bgs
- CVOCs in groundwater to >110’ bgs

- Valuable Urban Re-Development Location
  - >1 acre parcel
  - Designed for 540,000 SF mixed use space
  - Subsurface garage part of re-development



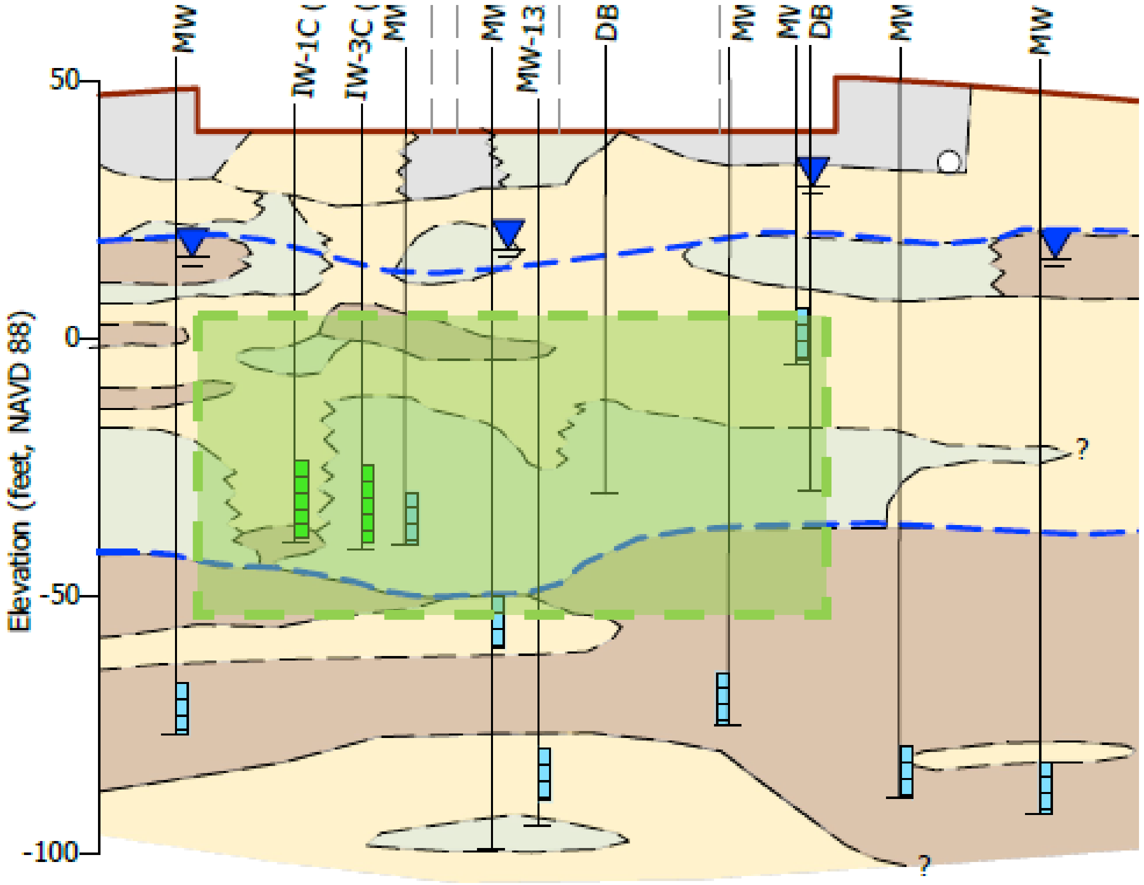
Combined Remediation Approach

- Vadose & Shallow Zone
  - 40-50 feet bgs
- Electric Resistance Heating
  - Objective – reduce soil concentration to not dispose excavated soils as hazardous waste
- Excavation for subsurface garage
  - 65,000 cubic yards
  - Focused chemical oxidation soil mixing where soil not treated by ERH



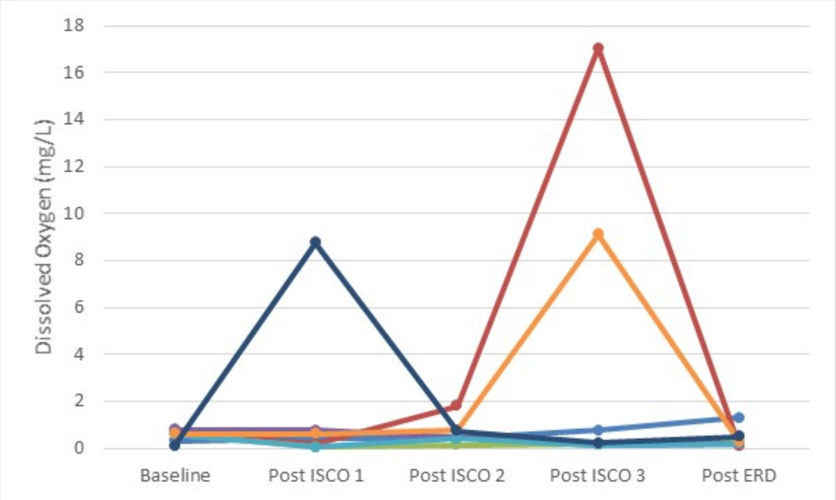
Combined Remediation Approach

- Intermediate Zone
  - 45-105 feet bgs
- In-Situ Chemical Oxidation
  - Modified Fenton's Reagent
  - Objectives: rapid mass reduction and enhanced desorption
  - 3 rounds in 4 months
- Enhanced Reductive Dechlorination
  - Objective: persistent, polishing treatment during construction



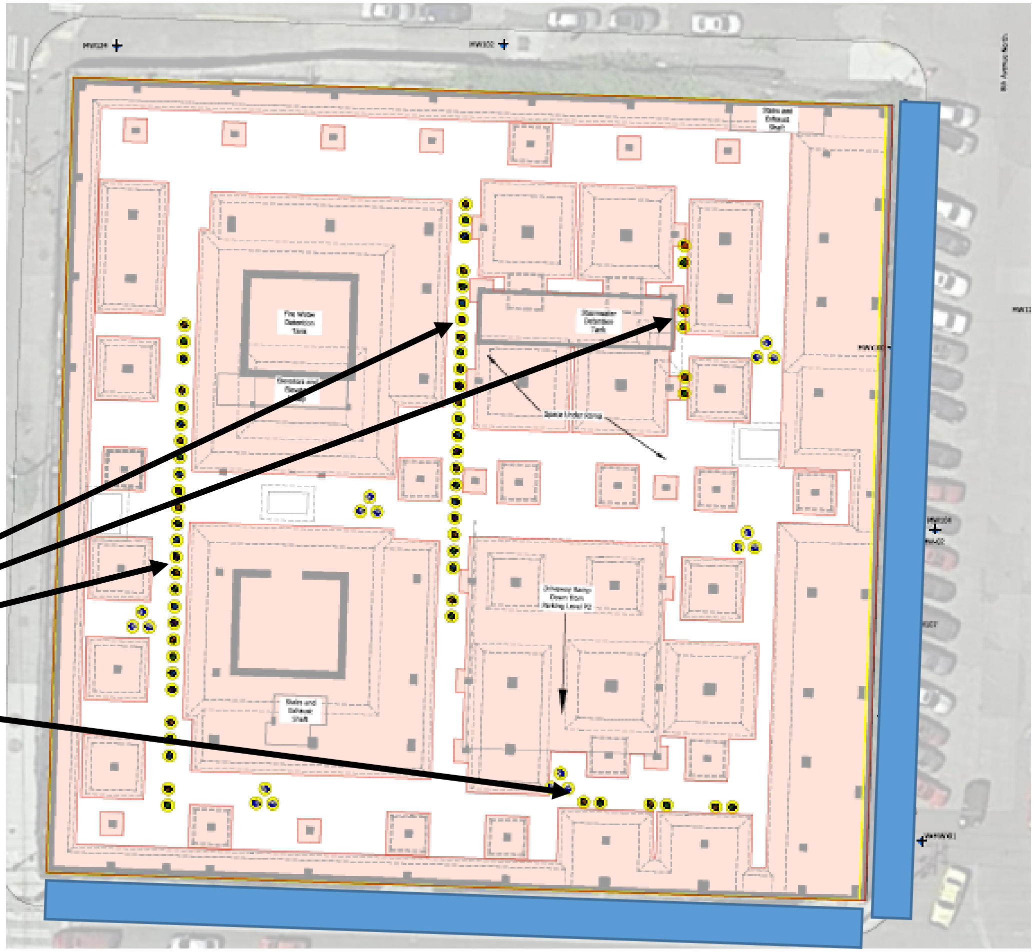
ERD Design within Combined Remedy

- Monitor DO and ORP during and after ISCO
  - ESTCP Substrate Design Tool sensitivity
- EVO as persistent donor
- Sodium lactate as quick-release substrate
- Deoxygenating amendment in all EVO batches
- EVO injection in phases
  - 20 consecutive days in February
- Bioaugmentation towards end of ERD injections
  - Negative ORP in all injection area MWs ~10 days after ERD



Combined Remedy Continued

- ERD Permeable Reactive Barrier
  - Minimize off-site migration of residual CVOCs
  - 4 vertical zones (45-105 feet bgs)
  - ~500 feet on east and south sides
  - EVO + Bioaugmentation
- Contingent Action Injection Wells
  - Already installed in basement
  - Anticipated ERD



Summary

- Technologies have advantages & disadvantages, strengths & limitations
- Build in Flexibility in technology selection, design, & implementation
  - Incorporate appropriate data collection
  - Know when to make adjustments (reactive or proactive combined remedy)
- Sequence technology implementation
  - Avoid adverse impacts for potential following technologies
  - Consider remedial byproducts: enhancement or inhibitor
- Conceptual Site Model & Geology

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Thank You

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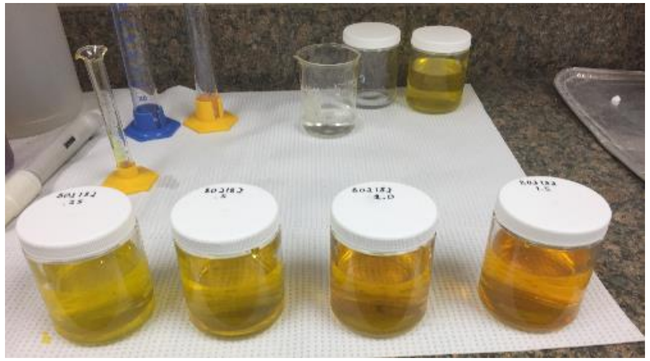
ISOTEC REMEDIATION TECHNOLOGIES


Chemical Oxidation & Reduction/Fixation


Bioremediation


Gas Thermal Conductive Heating


Soil Mixing (Chemical Reagents & Stabilization)


Treatability Laboratory


Activated Carbon Injectates (BOS100®, BOS200®)